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USING PAVEMENT TEXTURE TO SCREEN AND TARGET ANNUAL SKID NUMBER ASSESSMENT

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RESEARCH
Keeping Utah Moving
Utah Department of Transportation - Research Division
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16. Abstract

The purpose of this study is to develop an understanding of how pavement texture data can be used to inform roadway safety and develop a more targeted approach to Skid Number (SN) assessment with focus on high risk areas. Pavement texture data is a new data source for the Utah Department of Transportation (UDOT). Skid data and pavement texture data from 2017 were compared for a large, statewide dataset. Statistical analysis indicates there is not a strong correlation for SN and texture depth. Pavement texture, however, was found to be sensitive to surface type and some surface types represent a stronger correlation than others. Screening thresholds were developed for texture depth to help screen and refine skid data collection efforts for chip seal pavements. Cost saving estimates from using the screening thresholds for a case study result tens of thousands of dollars per year, however, given the duplication of screened out routes to reach areas to measure, the cost savings could be less. Texture thresholds were evaluated to target areas for skid data collection at more frequent intervals for stone matrix asphalt (SMA) pavements. Due to the weak skid data and texture data correlation, this method would still result in a portion of areas targeted for measurement that already have a good SN. A comparison of wet pavement crash history to pavement texture did not yield a strong correlation.

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ACW	Asphalt Concrete Wearing
GN	Grip Number
HFST	High Friction Surface Treatment
LCMS	Laser Crack Measurement System
MDE	Mean Depth of Elevation
MPD	Mean Profile Depth
MTD	Mean Texture Depth
PTV	Pendulum Test Value
ROGC	Rubberized Open Grade Course
SD	Surface Dressed
SMA	Stone Matrix Asphalt
SN	Skid Number
UDOT	Utah Department of Transportation

EXECUTIVE SUMMARY

The purpose of this study is to develop an understanding of how new pavement texture data can be used to inform roadway safety and develop a more targeted approach to Skid Number (SN) assessment with focus on high risk areas. Data collection for SN and pavement texture was provided by the Utah Department of Transportation (UDOT).

A statistical analysis searched for correlation between skid data and pavement texture. Findings from the statistical analysis indicate that there is not a strong correlation for SN and texture depth when looking at all pavement segments statewide. Pavement texture, however, is sensitive to surface type and some surface types represent a stronger correlation than others. Chip seal and untreated concrete pavements show the strongest correlation, especially when broken out by individual seal year. Focusing on last seal year, more recent seal years tend to exhibit more data points and stronger correlations than less recent seal years. Chip seal pavements show a weak positive correlation between texture depth and SN for each of the last seal years 2011 to 2017.

Screening thresholds were developed for texture depth to help screen and refine skid data collection efforts. When looking to screen out segments from future skid data collection, finding an optimal texture depth threshold is essential to minimize false positives or areas of poor or fair skid that should have been measured. The relative value of the threshold can be summarized in the effort saved by not having to collect data for true positive measurements that have a good SN and the risk in accepting some number of false positives.

In a case study, using a texture depth screening threshold of 0.05 inches to screen out segments from skid collection resulted in a high number of segments being screened out during a given year (70 percent in the chip seal example). Based on an hourly operating cost of $17 per mile for skid data collection, this would result in a savings of approximately $14,000 in data collection efforts when applied to the 2017 skid data collection efforts case study. Applying similar methods to the 2016 skid data collection, which was more comprehensive than 2017 data collection, the estimated savings are $23,000. However, given that the skid collection driver would still have to drive past many screened out segments to get to segments targeted for

measurement, the effort saved would be less. A conservative estimate reduces the 2017 and 2016 cost savings to approximately $4,500 and $7,000, respectively.

The texture depth screening threshold can also be used for a targeted approach to find areas to measure skid at more frequent intervals. Chip seal pavements and SMA pavements were examined and a texture depth of 0.04 inches was identified as a threshold for more frequent skid data collection. Applying this threshold to the 2017 skid-data-collection case study results in 180 miles of chip seal pavements and 60 miles of SMA pavements that would be targeted for more frequent skid data collection. This method was less efficient for the chip seal case study where 70 percent of the targeted areas corresponded with good skid conditions. For SMA, the split between areas with good skid and poor or fair skid was 50 percent.

Texture depth measures were aggregated to longer roadway segments defined by homogenous pavement types and ages. The total wet pavement crashes for each segment was compared to the average texture depth, but the result did not produce a strong correlation. Likewise, there was not a strong correlation between texture depth and the percent of wet pavement crashes as compared to all crashes.

Despite no strong correlation between texture depth and SN being manifest in this study, there is still enough of a relationship to apply meaningful thresholds to both screen skid data collection efforts and target skid data collection efforts to poor or fair skid areas. It is recommended that UDOT analyze and utilize annual texture data to tailor the annual skid data collection efforts. Further effort will be needed to determine how modified efforts affect real routing plans for skid data collection drivers.

1.0 INTRODUCTION

1.1 Problem Statement

Skid resistance and pavement texture data are important measures of pavement surface characteristics which ultimately affects the safety of every commuter during wet pavement conditions. However, there is little understanding of the correlation between the two and greater role that texture could play in ensuring safer highways.

The Utah Department of Transportation (UDOT) Performance Management Division invests considerable effort in collecting skid resistance data and conducts annual comprehensive Skid Number (SN) assessments on state highway pavements. Meanwhile, the annual pavement conditions survey now collects and reports pavement texture data. Though not a direct equivalent to the SN, studies by other agencies have shown pavement texture data demonstrates a correlation to pavement friction conditions. If the relationship holds true for conditions in Utah, then pavement texture data can be used as a screening tool to develop a more strategic data collection plan for SN assessments. Specifically, the Performance Management Division can target annual SN assessments for high risk areas and adjust data collection for low risk areas to less frequent intervals, thereby saving money and improving the utility of the data.

1.2 Objectives

The objective of the study is to develop an understanding of how new pavement texture data can inform roadway safety and target SN assessment to high risk areas.

1.3 Scope

1. Acquire and analyze statewide pavement texture measures.
2. Explore statistical correlation between texture measures and SN.
3. Define thresholds for SN assessment screening.
4. Explore the role texture data can play in ensuring safer highways and targeted skid collection.
5. Explore the statistical relationship between texture data and wet pavement crash history.
6. Document results and recommendations.

1.4 Outline of Report

This report contains six chapters including this introductory chapter. Chapter Two is a literature review of studies pertinent to the research subject matter. Chapter Three explains the methodologies used to perform this research. Chapter Four explains the data collection methods used to perform the analysis. Chapter Five details the research data analysis and findings. Chapter Six summarizes the research with conclusions and recommendations.

2.0 LITERATURE REVIEW

2.1 Background

This study investigates relationships between SN and pavement texture data. There have been several previous studies that have looked at similar correlations. This chapter contains summaries of existing research that relates to the subject matter.

2.2 Kansas Study

Zahir et al. (2016) evaluated road surface texture using 3-D laser data. The purpose of the study was to find a suitable correlation between SN and texture depth so that the traditional skid measurement can be supplemented by laser data for routine skid monitoring. Tests were carried out on three types of surfaces: surfaces with High Friction Surface Treatment (HFST) and Stone Matrix Asphalt (SMA) surfaces with SM 9.5A mix or SM 12.5A mix.

The key conclusions of this study include:

1. Texture depth and SN vary with pavement surface types
2. The Mean Texture Depth (MTD) of surfaces with high friction is generally greater than 1 mm (0.04 inches).
3. A good correlation between SN and texture depth was found in the range of 0.5 to 1.5 mm (0.02 to 0.06 inches) of texture depth for all three surface types.

2.3 Taiwan Study

Chou et al. (2017) investigated using a pavement texture index for skid resistance screening. Specifically, the research focuses on the development of a texture index that can serve as a screening indicator to filter out low risk pavement sections for further skid resistance measurement. The research used a texture index called Mean Depth of Elevation (MDE) as a screening method. A correlation between Grip Number (GN) and MDE was analyzed along with a method for determining a texture depth threshold that can screen out road segments with high GN.

Key conclusions of this study include:

1. MDE can be calculated by the profile data collected from pavement laser profilers to reduce the working load of skid resistance measurement on an entire network.
2. MDE and GN were found to have a positive correlation, but without a proven statistical relationship.
3. The selection of a MDE threshold is a trade-off circumstance, which should be selected based on minimizing the number of serious misjudgments (false positive measurements), where a segment with a low GN is screened out from measurement.

2.4 New Jersey Institute of Technology Study

Meegoda and Gao (2015) evaluated pavement skid resistance using high speed texture measurement. This research investigated the correlation between skid resistance and mean profile depth (MPD) on the macro surface texture so that highway agencies can predict the skid resistance of pavement without the use of expensive and time-consuming skid resistance trailer measurements. Skid data and MPD data from five new asphalt pavements and four old asphalt pavements were used for this research.

The key conclusions of this study include:

1. There is a positive correlation between SN and MPD for values less than 0.8 mm (0.03 inches).
2. The data trend shows a negative correlation with increasing MPD from 0.8 mm to 1.1 mm (0.03 to 0.043 inches).
3. Above 1.1 mm (0.043 inches), SN values remained constant with increasing MPD values.
4. The trend of correlation for old asphalt pavements is similar to that for new asphalt pavements, although the SN is lower for old pavements than for the new pavements.

2.5 Canadian Study

Ahammed and Tighe (2011) examined pavement surface texture and skid resistance as it relates to wet pavement crashes. Data was collected on nine different asphalt concrete surfaces.

The key conclusions of this study include:

1. The Superpave AC surface with premium aggregates was shown to exhibit the highest SN (SN 61) with a relatively low MTD among the tested surfaces.
2. Rubberized Open Grade Course (ROGC) with a good MTD was shown to exhibit the lowest SN (SN 44).
3. The model for the estimation of SN from the MTD and vehicle speed has shown a fair correlation. ($R^2 = 0.56$).
4. Excellent correlation was found ($R^2 = 0.98$) between aggregate quality and good surface friction.

2.6 Malaysian Study

Yero et al. (2012) researched the correlation between the pendulum test value (PTV), texture depth, and roughness index on six selected test road surfaces. The study evaluated three surface types: SMA, asphalt concrete wearing (ACW) and surface dressed (SD).

The key conclusions of this study include:

1. The correlation between the texture depth and the roughness index on SD pavement is weak, while SMA and ACW indicated no correlations.
2. Roughness Index values were only in the acceptable range for SD pavement and were higher than the maximum acceptable threshold for ACW and SMA surfaces.

3.0 METHODOLOGY

3.1 Overview

Several different data collection methods were used in the examination of the relationship between skid resistance and pavement texture data. The following sections detail the characteristics of the data used in this analysis and the methods used to evaluate it.

3.2 Skid Data

Skid is a measurement of pavement friction. UDOT collects an annual inventory of skid data for state highway pavements and reports results in terms of the unitless SN. The higher the SN, the more friction manifest by the pavement section. Table 3.1 defines the threshold used by UDOT to convert SN into a categorical assessment of pavement friction condition.

Table 3.1 SN Thresholds

Skid Condition	SN
Good	> 45
Fair	35 – 45
Poor	< 35

The annual UDOT skid data assessment is performed with the locked wheel skid trailer methodology. A trailer towed by a truck sprays water on one of the trailer wheels. Then, the same wheel is locked via a braking mechanism. The resistance force of the locked wheel is recorded and converted to a SN. Skid measurements are collected at 0.5 mile intervals, though the interval may be reduced to 0.1 miles in areas where further investigation is desired.

Figure 3.1 UDOT Skid Data Collection Truck and Trailer

Figure 3.2 Spray Nozzle

3.3 Texture Data

Texture data is a reflection of the smoothness or roughness of a pavement surface. There are a variety of ways to measure texture data. Traditionally, texture data has been measured via the sand patch method where a quantity of sand is poured and smoothed over a pavement area. The volume of sand divided by the area of the sand coverage indicates the average depth of pavement particles or the average roughness of the pavement.

An alternative to the sand patch method is to collect texture data via a laser crack measurement system (LCMS). With this method, a laser will continuously scan a pavement surface and record the differences in pavement particle height. The average particle height is calculated and reported as the texture depth for the pavement area.

3.4 Microtexture vs. Macrotexture

Pavement texture can be measured at various scales. The microtexture scale is commonly understood to measure the surface profile of individual aggregate particles in a pavement. Microtexture is often expressed in at the scale of thousandths of an inch. Macrotexture is commonly understood to represent the overall profile of the pavement surface. Macrotexture is on the scale of hundredths of an inch. Figure 3.3 and Figure 3.4 illustrate the concepts of microtexture and macrotexture.

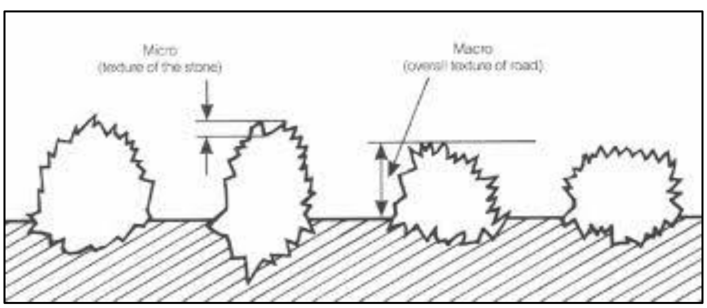


Figure 3.3 Scale of Macrotexture vs. Microtexture (Meegoda 2009)

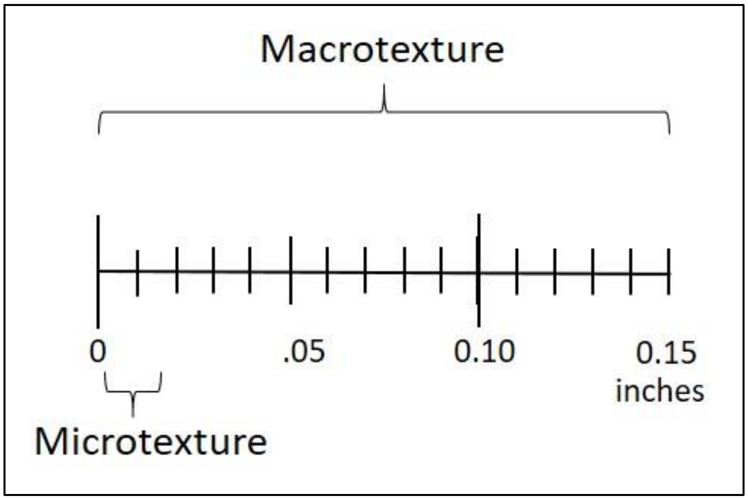


Figure 3.4 Scale of Macrotexture vs. Microtexture

3.5 Texture Measurement Methods

There are multiple ways to compute pavement texture. Three methods commonly used include:

1. MTD
2. MPD
3. MDE

MTD is a volume-based method that averages the particle depths in relation to the highest point in a known area. The sand patch method computes MTD. MPD is a two-dimensional measure of pavement profile. MPD is the average of the two peak profiles of two halves of a given measurement area (see Figure 3.5). MDE is a texture index reflecting the average difference in elevation at fixed intervals along a pavement profile (see Figure 3.6).

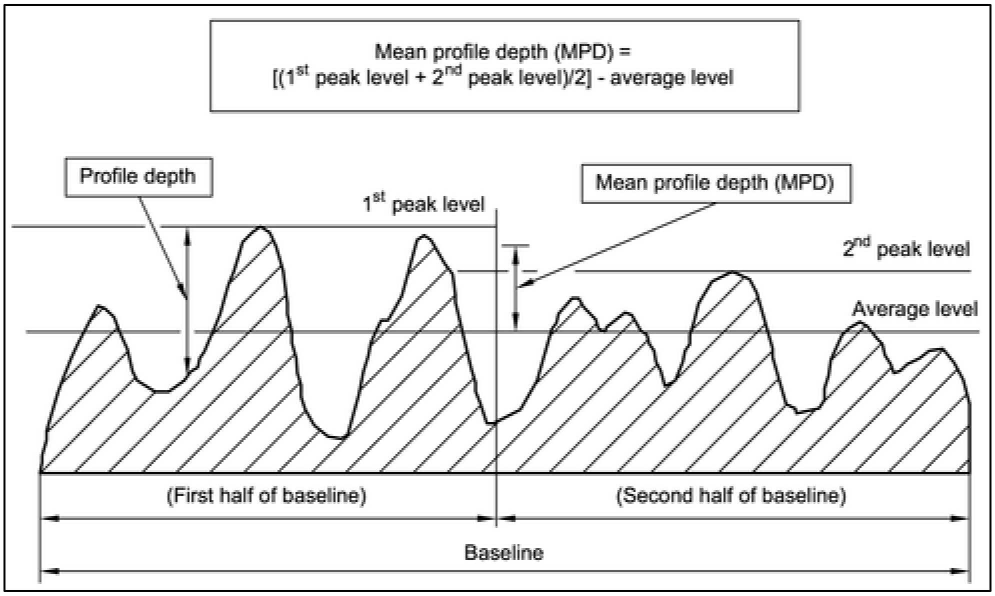


Figure 3.5 Illustration of MPD Calculation (ISO 2018)

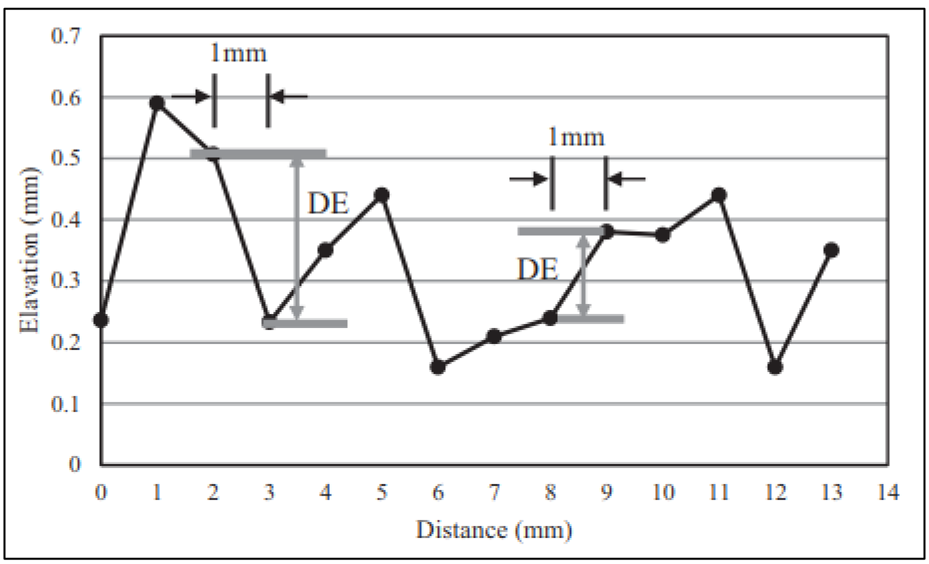


Figure 3.6 Illustration of MDE Calculation (Chou, et al 2017)

4.0 DATA COLLECTION

4.1 Overview

Data collected for this research study was gathered from multiple sources and agencies. This chapter details how and why skid data and pavement texture data are collected, which make up the two key data sets of this analysis. Other roadway characteristics collected are also discussed.

4.2 Skid Data

UDOT provided skid data from the 2017 and 2016 skid data collection efforts. The 2017 skid dataset had less coverage than typical years due to UDOT staffing shortages. The 2017 data represented over 10,400 data points covering approximately 4,700 miles of the state highway system. In comparison, the 2016 skid data represented about 12,300 data points covering approximately 5,300 miles.

Though the 2017 skid data have fewer data points than 2016, the 2017 data was used because it was collected the same year as the texture data and would reflect friction conditions of the pavement the time the texture data was collected more accurately than the 2016 skid data.

4.2.1 Measurement Intervals

Most 2017 skid data points were collected at 0.5 mile intervals. A few targeted areas, representing about eight percent of the data set, were collected at more frequent intervals, such as every 0.10 miles. These were generally areas of interest due to abnormal SN results, past poor pavement condition, or a history of safety concerns.

4.3 Texture Data

UDOT provided pavement texture data from the 2017 asset inventory. Among other things, the asset inventory included a laser scan of the roadway and surrounding area, photo images, and pavement condition assessments. Texture data was one of the pavement condition assessments and was collected via the LCMS method discussed previously and was reported as MTD.

The 2017 texture dataset covered the entire state highway system. Texture measurements were made continuously and aggregated to 0.1 mile segments. Texture measurements were reported for three locations on the pavement cross section:

1. Left-wheel path
2. Between-the-wheel paths
3. Right-wheel path

Because the focus of the analysis is the relationship of vehicle contact with pavement, the texture data between the wheel paths were not used. Additionally, results showed that between-the-wheel path data tended to have greater depth than the left or right wheel paths presumably due to the lack of pavement wear from vehicle tires (see Figure 4.1). Furthermore, to simplify the methodology, only data from the left wheel path were used for analysis because results indicate texture depths for left-wheel path and right-wheel path measures are similar. There were a total of 59,169 texture data points for the left wheel path. Less than one percent of the data points (679) featured a zero or null value and were screened from analysis leaving 58,490 data points.

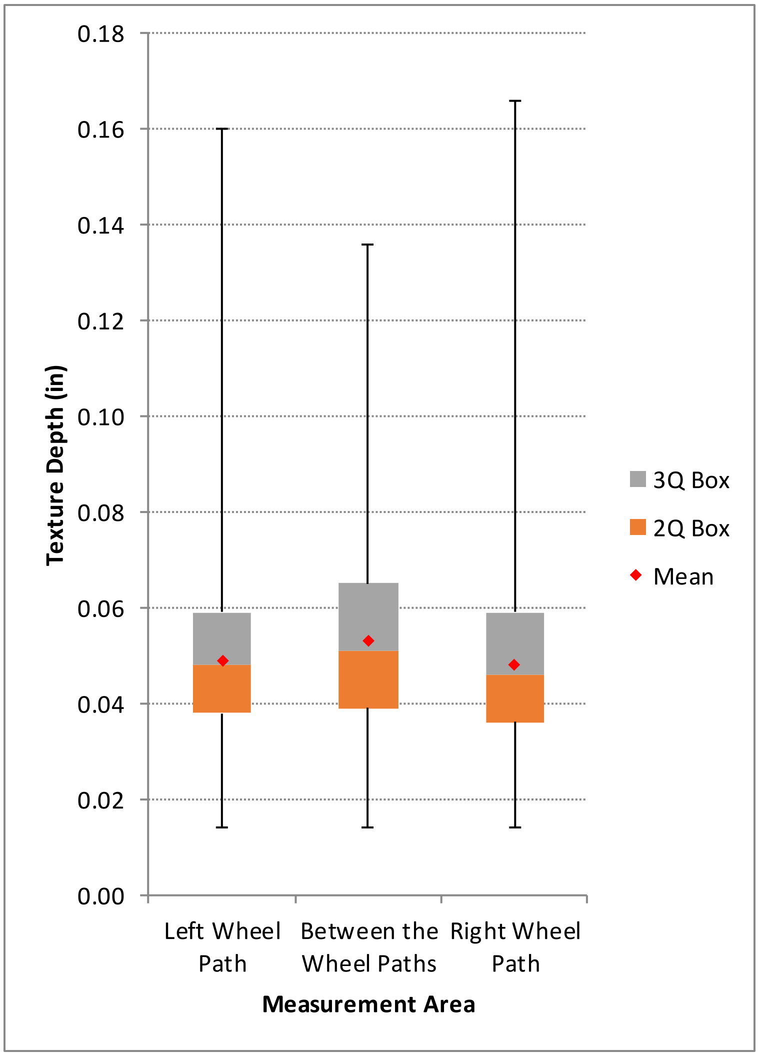


Figure 4.1 Texture Measurement Area Comparison

4.4 Other Roadway Characteristic Datasets

In addition to skid and texture data, UDOT provided additional datasets related to pavement and roadway conditions. First, UDOT provided the 2017 pavement section dataset. This dataset divides the state highway system into segments of homogenous surface type. The dataset includes attributes such as pavement surface type and the last seal year.

UDOT also provided a five-year (2013-2017) dataset of pavement crashes on the state highway system. The crash dataset included the route and milepost of the crash, the date of the crash, and the roadway surface condition. For the purposes of this study, crashes were classified as a “wet pavement crash” if the roadway surface condition attribute was coded as “wet” or “water (standing, moving)”.

4.5 Summary

Data collected for this research study focuses on two main data sets: skid data collection and pavement texture data. The skid data set is provided by UDOT and covered 4,700 miles of the state highway system in 2017 and 5,300 miles of the state highway system in 2016. The 2017 collection effort is the primary data set used in the study. Pavement texture data for the 2017 year is provided by UDOT using a laser scan. Pavement texture measurements cover the entire state highway system and are aggregated to 0.1 mile segments.

5.0 ANALYSIS

5.1 Overview

The correlation between pavement texture data and skid data was analyzed for the entire state highway system in Utah. The purpose of the analysis is to determine if there is a relationship between texture data and skid data, and how this data can be used to target certain areas of the state for more efficient skid data collection to maximize time and resources. Additional analysis examines the relationship between texture and safety.

5.2 Data Evaluation

Pavement texture data was evaluated against several different data types including surface type, SN, SN by surface type, and last seal year to examine the relationship between texture data and these other available data sets. The purpose of this data evaluation was to find meaningful correlation to aid in a more efficient skid data collection effort in the future.

5.2.1 Texture and Surface Type

The first area of analysis for the texture data was the relationship with pavement surface type. As mentioned, previously, UDOT maintains a statewide classification of roadway segments by pavement surface type. The range of pavement texture values for each surface type is shown in the box plots in Figure 5.1.

Several observations can be made from the data. Chip seal surfaces comprise more than half of the pavement surface type dataset. Second, asphalt surface types (the first six box plots from the left) have much higher average texture depth than concrete surface types (the last two box plots on the right). Average texture depths for asphalt surface types range from just under 0.04 inches to about 0.06 inches. The concrete surface types have average texture depths a little above 0.02 inches. It should be noted that the slurry seal surface type was excluded from the analysis because of a low sample size – 190 data points. Likewise, gravel surfaces were also excluded.

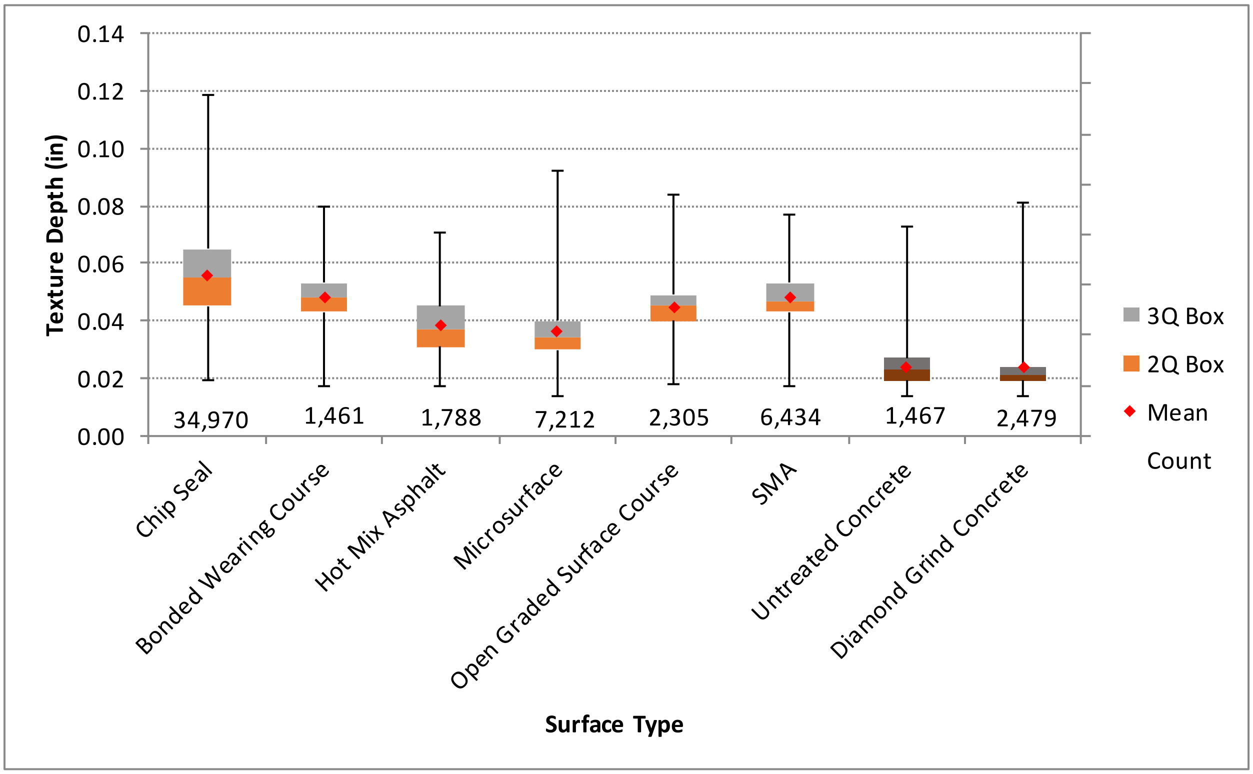


Figure 5.1 Box Plots of Texture Depth by Pavement Surface Type

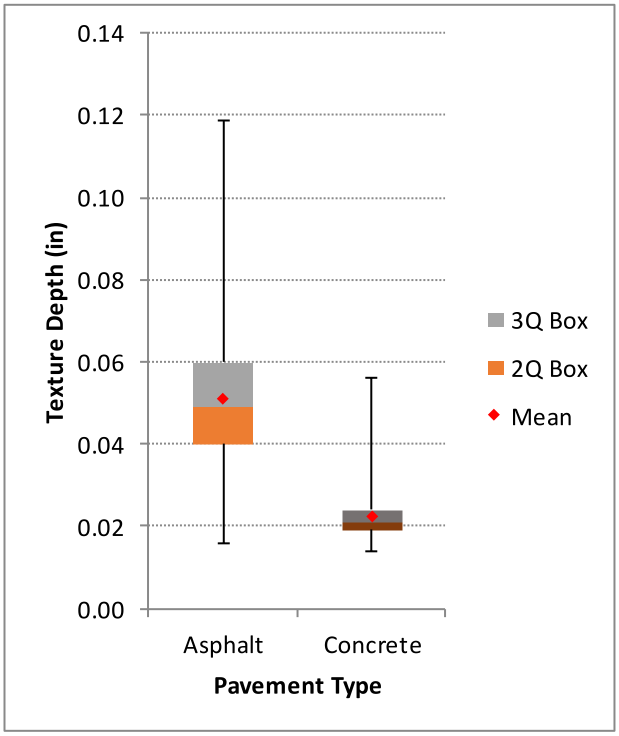


Figure 5.2 Box Plots of Texture Depth: Asphalts vs. Concretes

A basic, Student's T-test for statistical significance indicates there are differences in the texture depth ranges among individual pavement surface types. Table 5.1 summarizes the p-values for combinations of pairs of surface types. A p-value below 0.05 indicates with 95 percent confidence that the differences in texture depth between two surface types are statistically significant. As seen in Table 5.1, all but two surface type pairs have p-values below 0.05. Bonded wearing course asphalts and SMA, as well as untreated concrete and diamond-grind concretes, have p-values above 0.05. The texture depth values in these two comparison pairs do not exhibit a statistical difference.

This distinction between texture depths for various surface types, especially the distinction between asphalts and concretes is an important factor in the analysis methodology.

Table 5.1 Student's T-Test for Texture Depth and Pavement Surface Type

P-values[1]	Bonded Wearing Course	Hot Mix Asphalt	Micro-surface	Open Graded Surface Course	SMA	Untreated Concrete	Diamond Grind Concrete
Chip Seal	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Bonded Wearing Course	--	< 0.01	< 0.01	< 0.01	0.20	< 0.01	< 0.01
Hot Mix Asphalt	--	--	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Microsurface	--	--	--	< 0.01	< 0.01	< 0.01	< 0.01
Open Graded Surface Course	--	--	--	--	< 0.01	< 0.01	< 0.01
SMA	--	--	--	--	--	< 0.01	< 0.01
Untreated Concrete	--	--	--	--	--	--	0.75

1. Two-sample, unequal variance test

5.2.2 Macrotexture and Skid

As discussed in the literature review, some studies have found a meaningful relationship between pavement friction and pavement texture. The strength of the relationship can vary depending on the surface type, condition, or aggregate type or quality.

Figure 5.3 plots the texture data points and their corresponding skid measurement. Of the 58,490 texture data points that had a non-zero or non-null value, 8,082 occurred in a location with a 2017 skid measurement. The plot indicates the correlation for SN and texture depth is not strong. The R-squared value is less than five percent.

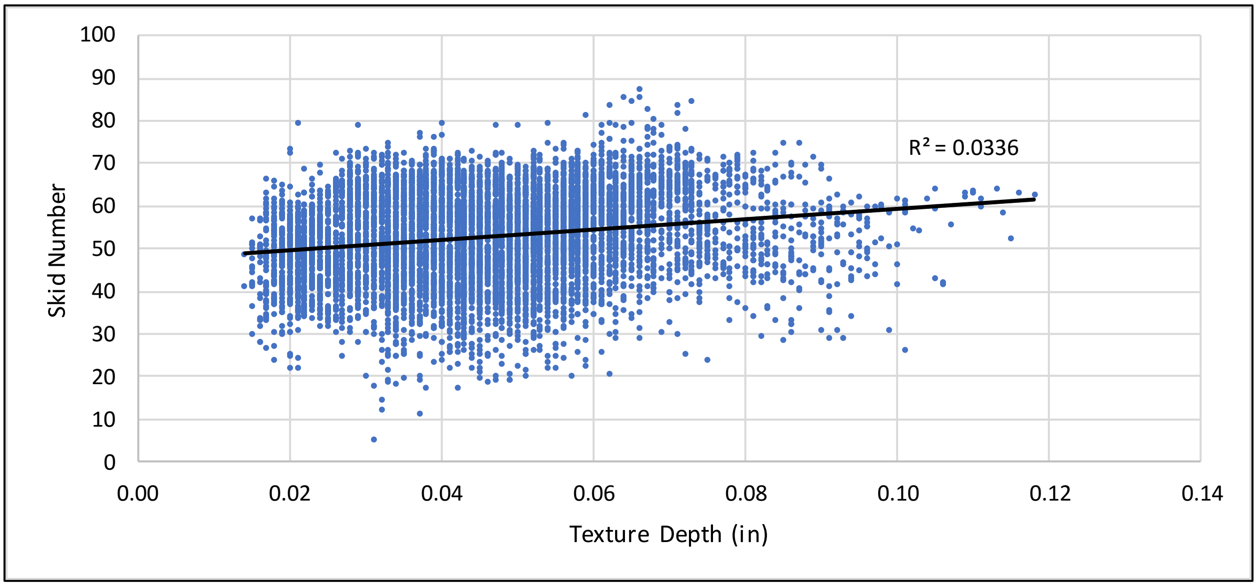


Figure 5.3 SN and Texture Depth for All Data Points

5.2.3 Macrotexture vs SN by Surface Type

With the understanding that texture data is sensitive to surface type, the comparison between skid data and texture data was then conducted for groupings of surface types. Figure 5.4 and Figure 5.5 illustrate the patterns for concrete and asphalt surface types, respectively. Again, slurry seal and gravel data points are omitted.

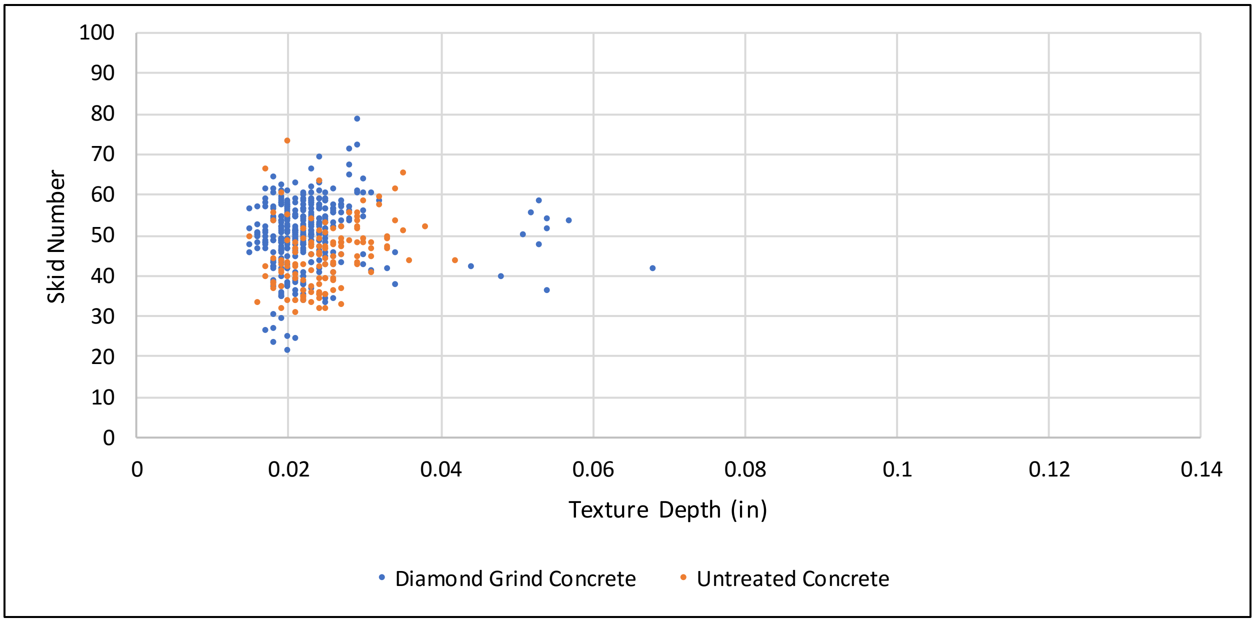


Figure 5.4 SN and Texture Depth for Concrete Segments

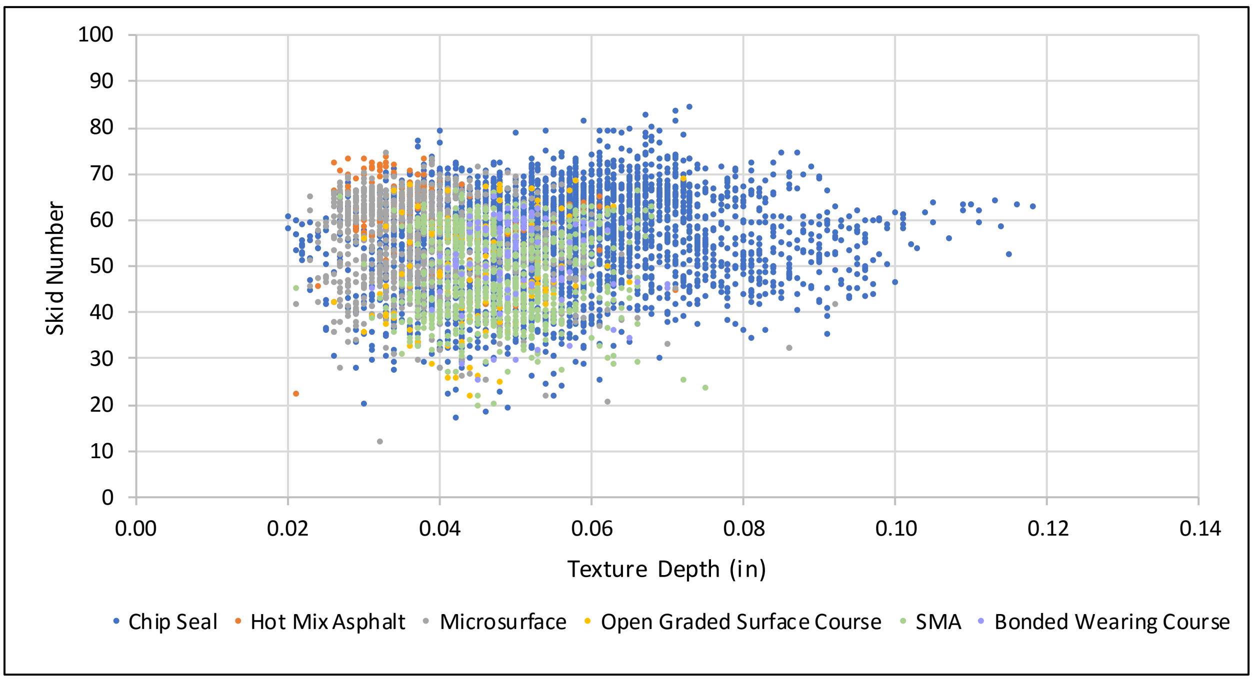


Figure 5.5 SN and Texture Depth for Asphalt Segments

No single surface type manifests a convincingly strong correlation between skid and pavement texture, but some are stronger than others. Figure 5.6 and Figure 5.7 isolate the skid and texture relationship for each surface type. The highest R-squared value for any surface type is eight percent for untreated concrete. Some surface types exhibit a negative correlation.

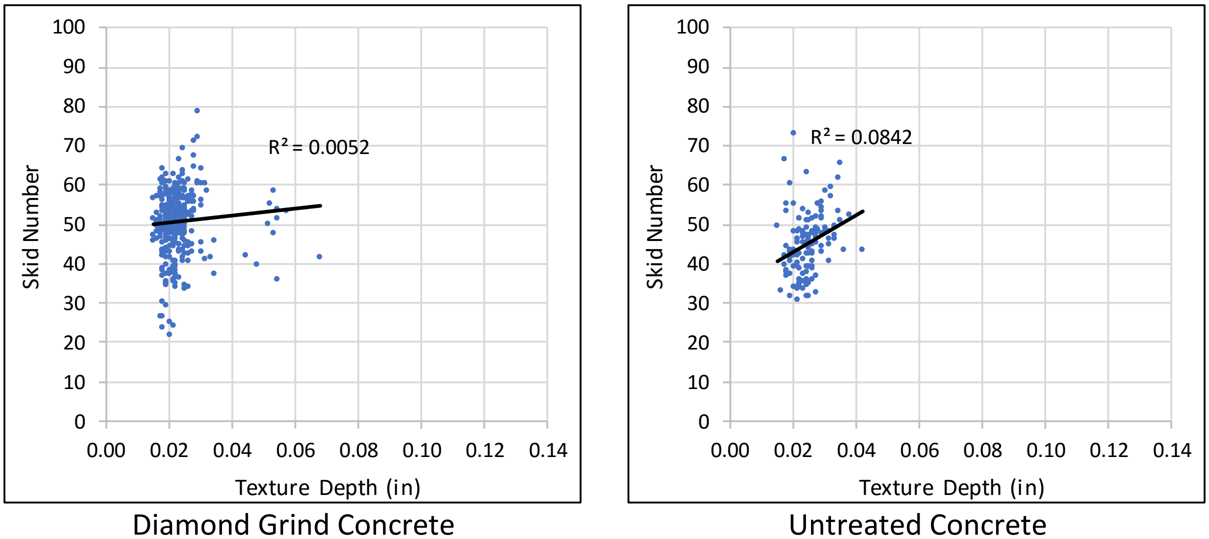
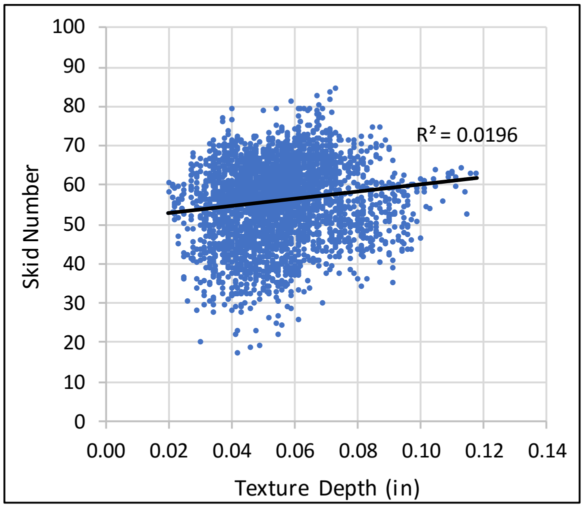
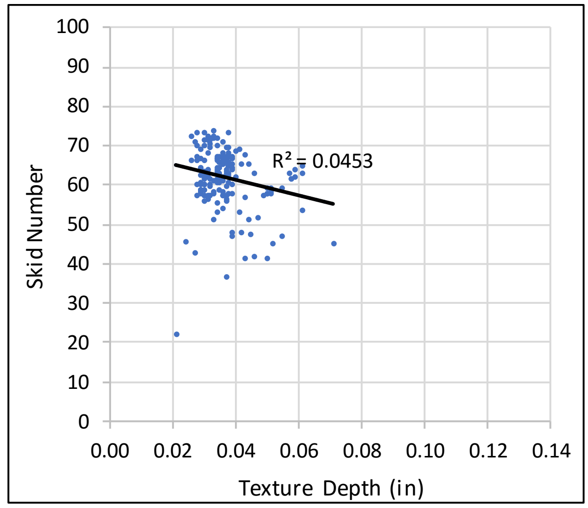


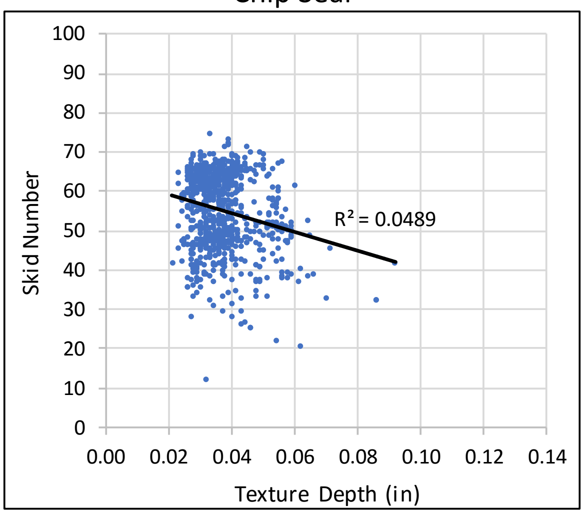
Figure 5.6 SN and Texture Depth R-squared Values for Concrete Segments



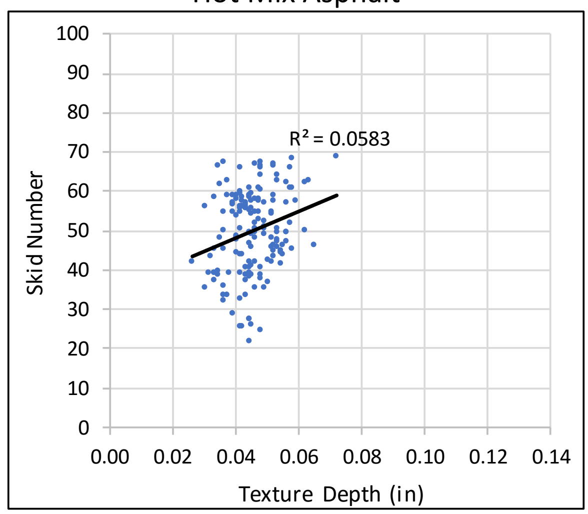
Chip Seal



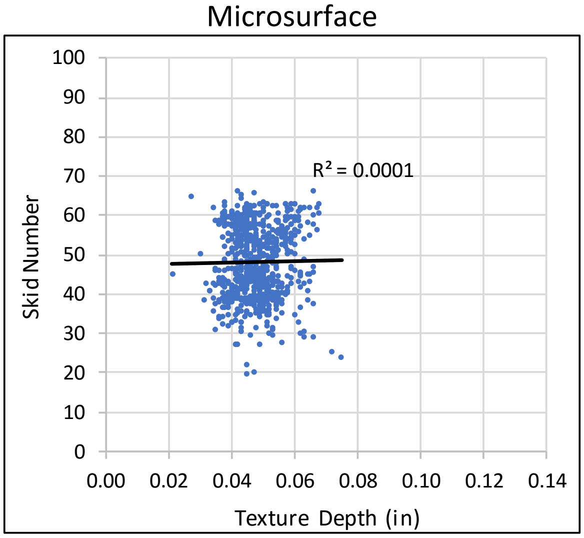
Hot Mix Asphalt



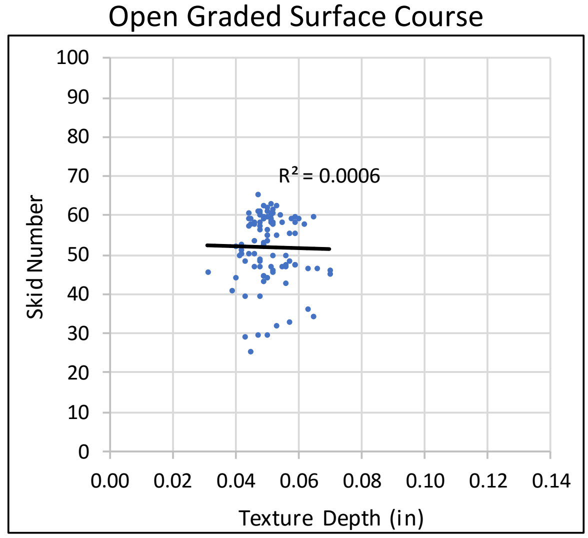
Microsurface



Open Graded Surface Course



SMA



Bonded Wearing Course

Figure 5.7 SN and Texture Depth R-squared Values for Asphalt Segments

5.2.4 Macrotexture vs SN by Last Seal Year

The relationship between texture data and skid data was next examined according to surface type and the date of the last seal year. Figure 5.8 plots SN and texture depth for chip seal pavements for individual seal years from 2017 to 2012. Figure 5.9 plots seal years from 2011 to 2006. Though correlation can vary from seal year to seal year, more recent seal years tend to exhibit more data points and stronger correlations than less recent seal year. This trend was found to be consistent with most other surface types.

The SMA pavement texture and skid relationship exhibits a trend worth mention. Anecdotally, there have been concerns in Utah about the friction properties of newer SMA applications. The perception is that new SMA applications have reduced friction properties, but after a year or two, as the pavement wears, the friction increases. Figure 5.10 depicts the skid and texture relationship for SMA pavements with a seal year from 2017 to 2014. The data illustrate a trend where pavements with seal years within the latest three years exhibit a negative correlation between skid and texture, whereas, pavements with a 2014 seal year show a positive correlation.

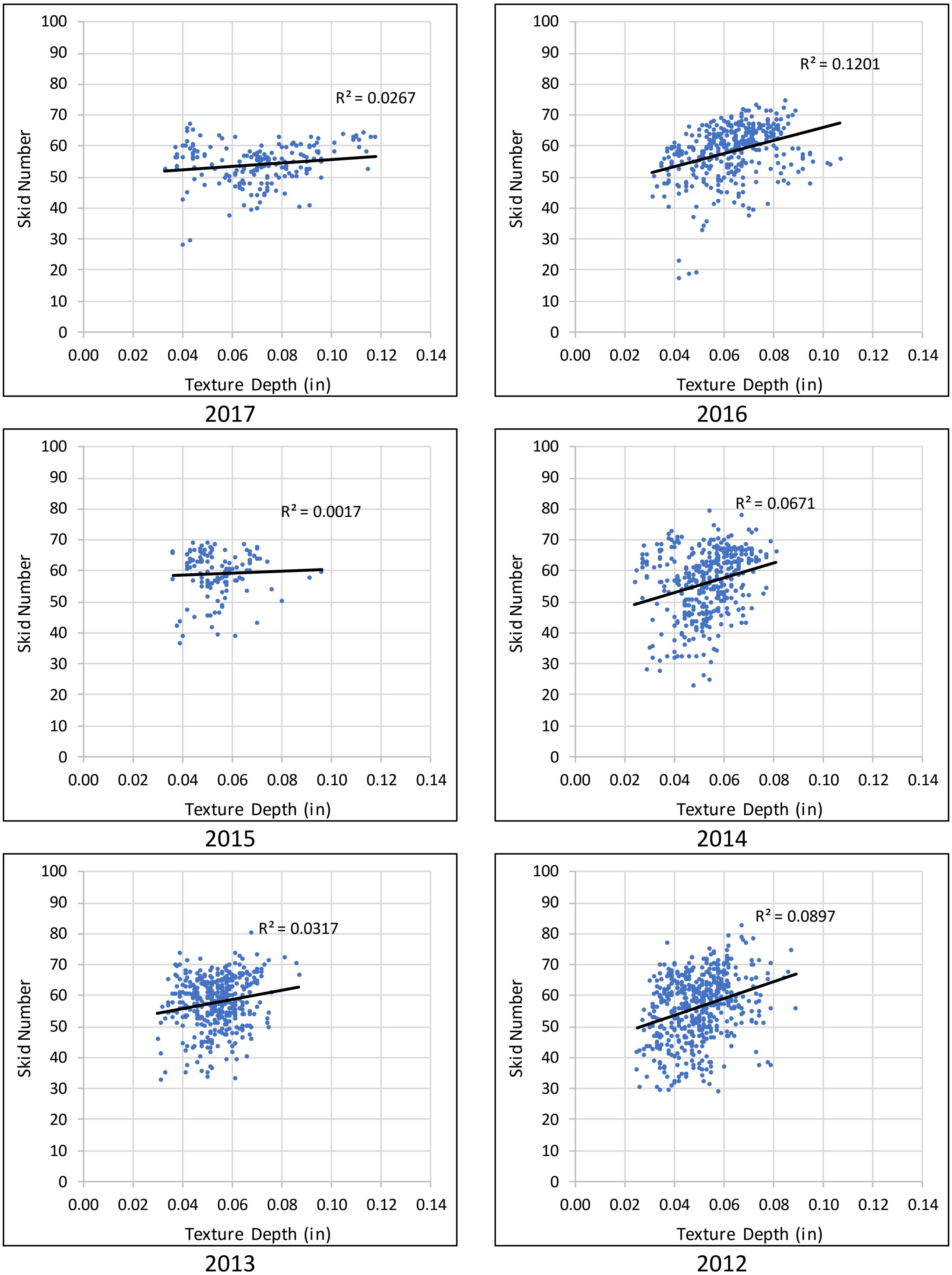


Figure 5.8 SN and Texture Depth for Chip Seal Pavements by Last Seal Year (2017-2012)

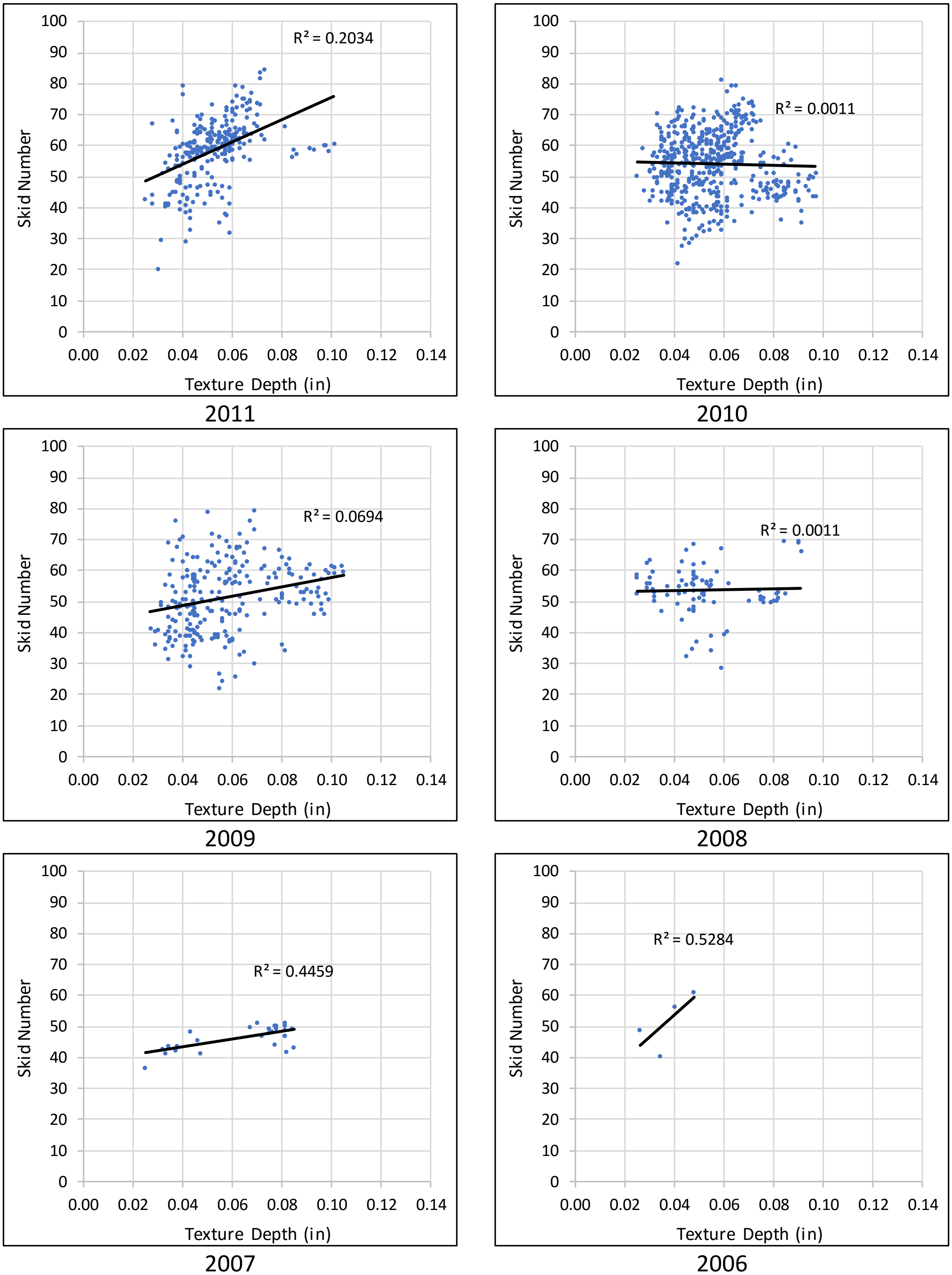


Figure 5.9 SN and Texture Depth for Chip Seal Pavements by Last Seal Year (2011-2006)

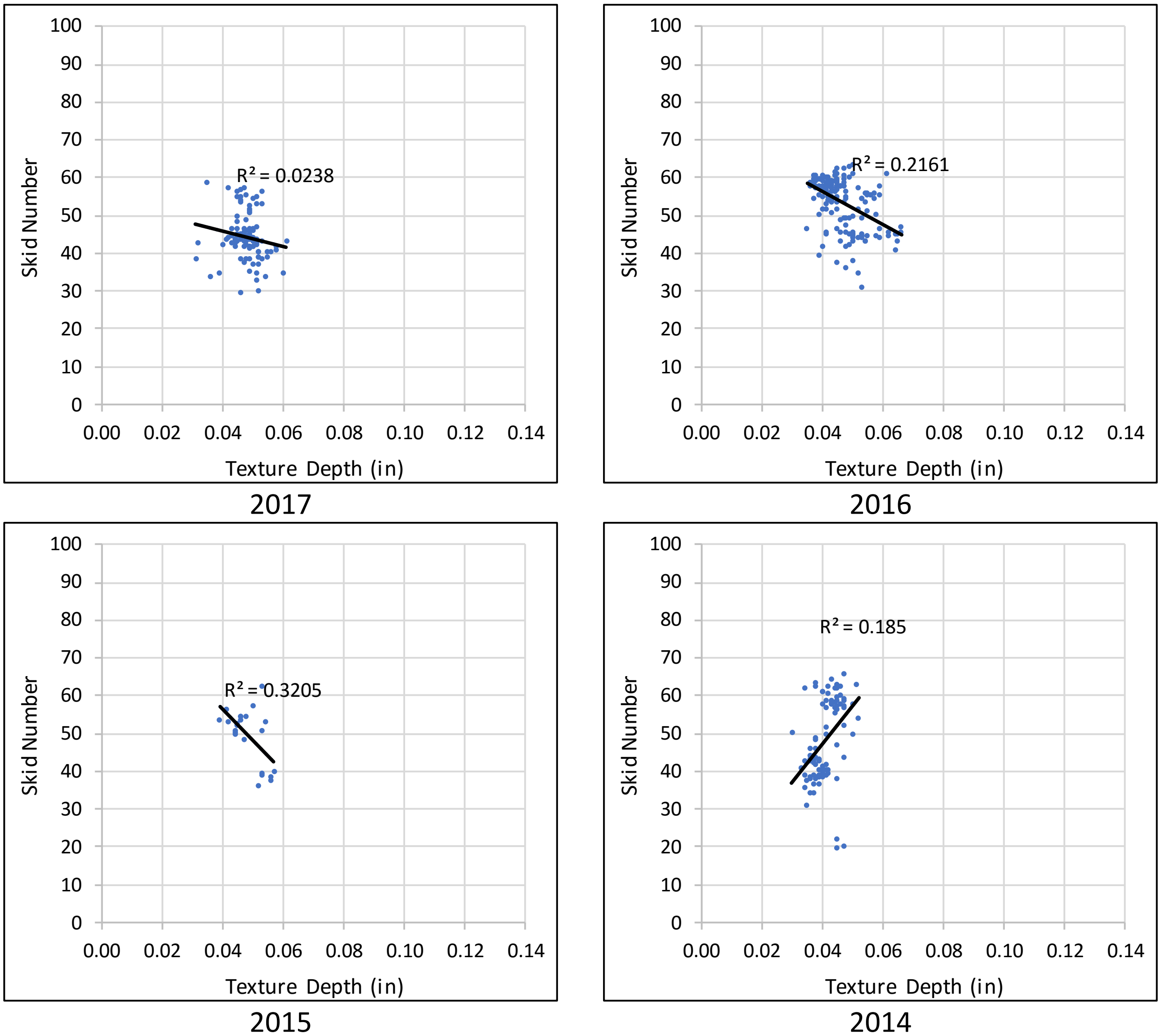


Figure 5.10 SN and Texture Depth for SMA Pavements by Last Seal Year (2017-2014)

5.3 Screening Thresholds

The next step in the analysis is an investigation of the utility of using the skid data and texture data relationship to identify texture depth thresholds to help screen and refine skid data collection efforts.

5.3.1 Threshold Optimization

The methodology used to analyze potential screening thresholds was modeled after a method used by Chou et al. (2017). The methodology involves defining an acceptable SN threshold and then varying the potential texture depth screening threshold while quantifying various proportions of data points falling in the following four categories:

A. True positives
B. False negatives
C. True negatives
D. False positives

For example, Figure 5.11 illustrates the sample categorization of data points for chip seal pavements with a seal year between 2012 and 2017. For this sample categorization, the SN threshold is set at 45 and the texture depth threshold is set at 0.04 inches. As documented previously, this SN threshold is the delineation between good skid and fair or poor skid. The texture depth threshold of 0.04 inches is arbitrarily set for illustrative purposes.

Figure 5.11 can be used to illustrate the effectiveness of a potential process to screen and refine skid data collection with these thresholds. For example, the pavements representing data points with texture values less than the threshold of 0.04 inches would undergo skid data collection while the pavements representing the data points with texture values greater than 0.04 inches could be screened out from data collection. Meanwhile the data points below the SN threshold of 45 represent pavements that have poor or fair skid conditions while the data points above 45 represent pavements with good skid condition.

Thus, the data points above a SN of 45 and greater than a 0.04 inch texture depth (quadrant A) represent pavements that feature a good SN and would accurately be screened out from the data collection process. These are true positives and represent improved efficiencies in the data collection process because unnecessary effort in collecting data for pavements with good skid is eliminated.

Quadrant B data points also have a good SN, but the low texture depth did not result in them being screen out of the skid data collection. To some degree, this represents wasted efforts because resources would be spent gathering measurements on pavements with good skid. Quadrant C data points are pavements with a fair or poor SN and the corresponding low texture depth correctly kept them in the category of needing skid data collection. Quadrant D data points represent the most risk. These are pavements where the texture depth was high enough to suggest they can be screened out from skid data collection but the skid condition is fair or poor.

The optimal texture depth screening threshold will maximize the proportion of data points classified as true positives and true negatives (quadrants A and C) while minimizing the false negatives and false positives (quadrants B and D) of the dataset. Without a perfect skid data and texture data correlation, no screening threshold will result in 100 percent of the data being true positives and true negatives. However, the relative value of the threshold can be understood in the context of the effort saved not collecting skid data for true positives and the risk in accepting some number of false positives.

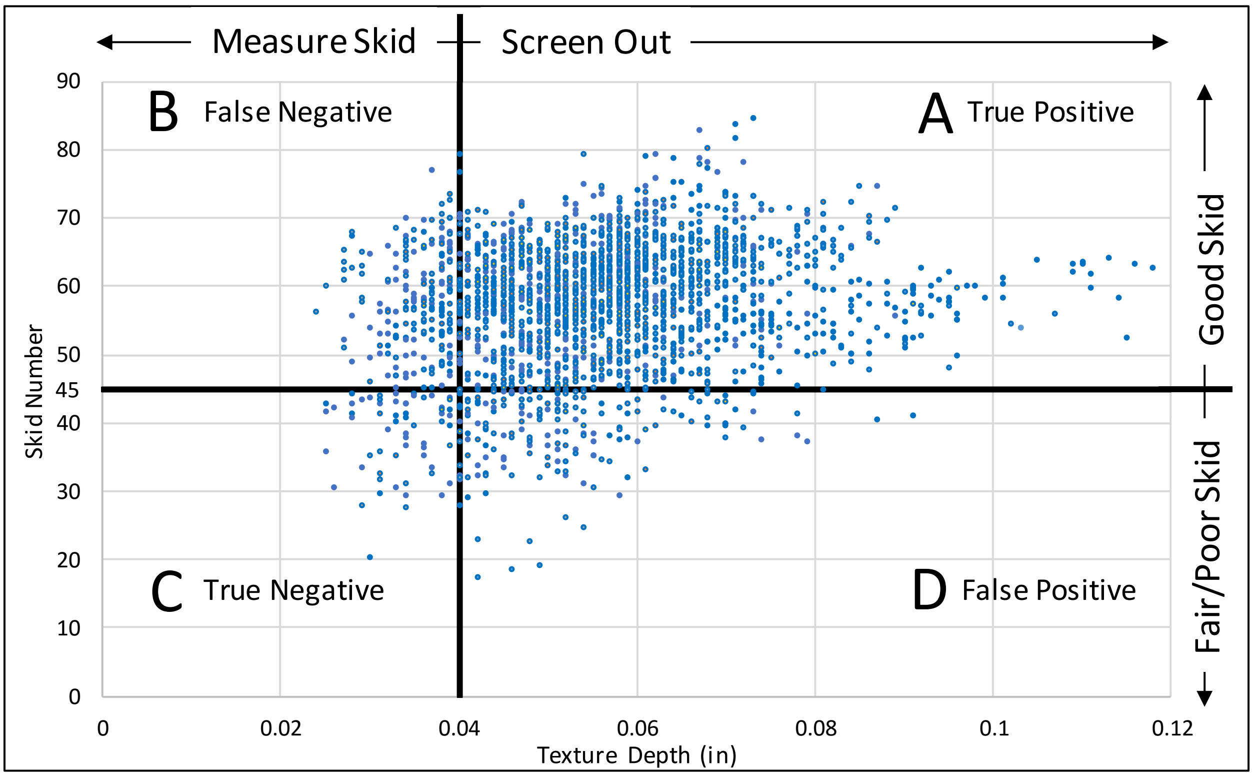


Figure 5.11 Sample Screening Thresholds for Chip Seal Pavements with 2017-2012 Seal Year

One method to visualize the balance between efficient skid data collection and false positive risks – again utilized by Chou et al. (2017) – is to plot relationships between the percentages of data points falling within each quadrant for a range of texture depth thresholds. Figure 5.12 illustrates the varying percentage of data points for three metrics for chip seal pavements with a seal year between 2012 and 2017. First, Figure 5.12 plots the percentage of data points in quadrant D (false positives). Ideally, this percentage should be as low as possible. Second, the chart plots the combined percentages of data points in quadrants A and C (true positives and true negatives). Ideally, this value should be as high as possible. Finally, the chart plots the data points in quadrant C (true negatives) divided by the sum of data points in quadrants C and D (true negatives and false positives). This represents the proportion of all data points with poor skid condition that would be still be a part of the skid data collection plan. Ideally, this metric should also be as high as possible.

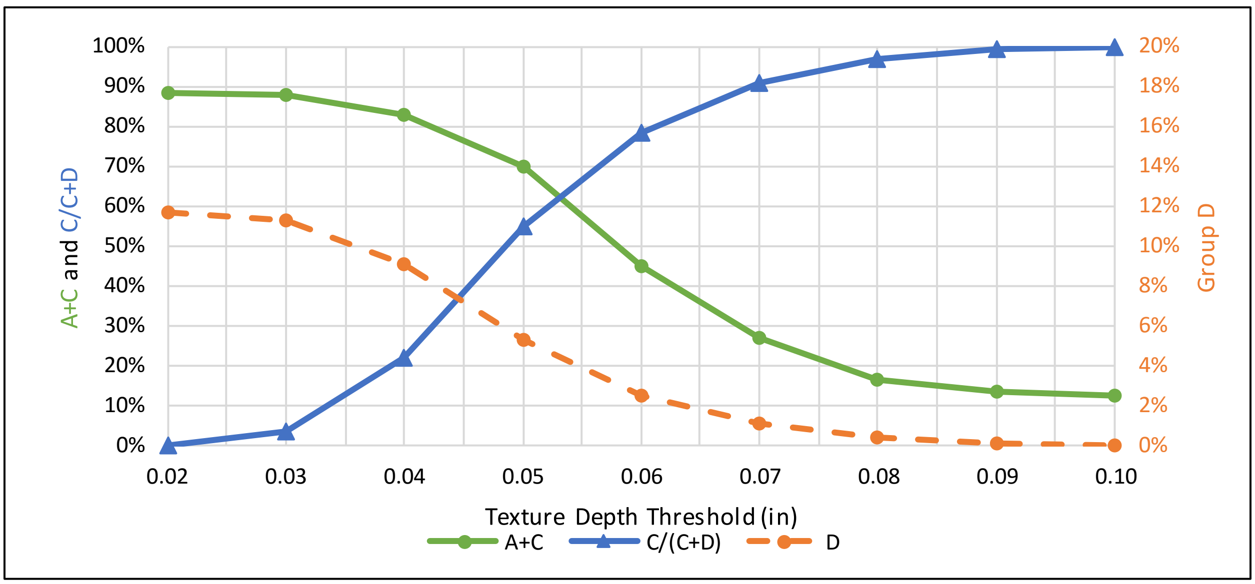


Figure 5.12 Varying Texture Depth Threshold for Chip Seal Pavements with 2017-2012 Seal Year

For the example depicted in Figure 5.12, the A+C line decreases as the texture depth threshold increases. Lower texture thresholds will have higher percentages of data points in quadrants A and C. However, the lowest texture thresholds also have the highest percentages of false positives (quadrant D). Likewise, low texture thresholds also correlate with lower percentages for the C/(C+D) line. Thus, the more optimal texture thresholds will be located some distance after the D line has decreased from its high point and the C/(C+D) line has experienced its biggest growth, but before the A+C line has decreased significantly. In this analysis, a texture depth threshold of 0.05 inches was selected for this dataset. This correlates with an A+C value of 55 percent, meaning just over half of the data points that actually have fair or poor skid would still be measured. Meanwhile the amount of data points that are true negatives and true positives is 70 percent. Finally, the percentage of false positives is about five percent.

Figure 5.13 displays the varying percentages of metrics for untreated concrete pavements with a seal year between 2012 and 2017. Unlike chip seal pavements, there are diminished options for a texture depth threshold that results in good percentages for each metric. For example, a threshold of 0.03 inches results in a low percentage for the D line (about 2 percent), but the A+C line is only at 47 percent, meaning less than half of the data points are true negatives or true positives. In fact, most are false positives or false negatives.

Because of a lack of strong correlation between skid data and texture data, other surface types also have metrics that do not support useful options for texture depth thresholds. Figure 5.14 and Figure 5.15 Illustrate the metrics for two of the other more common surface types: microsurface and SMA.

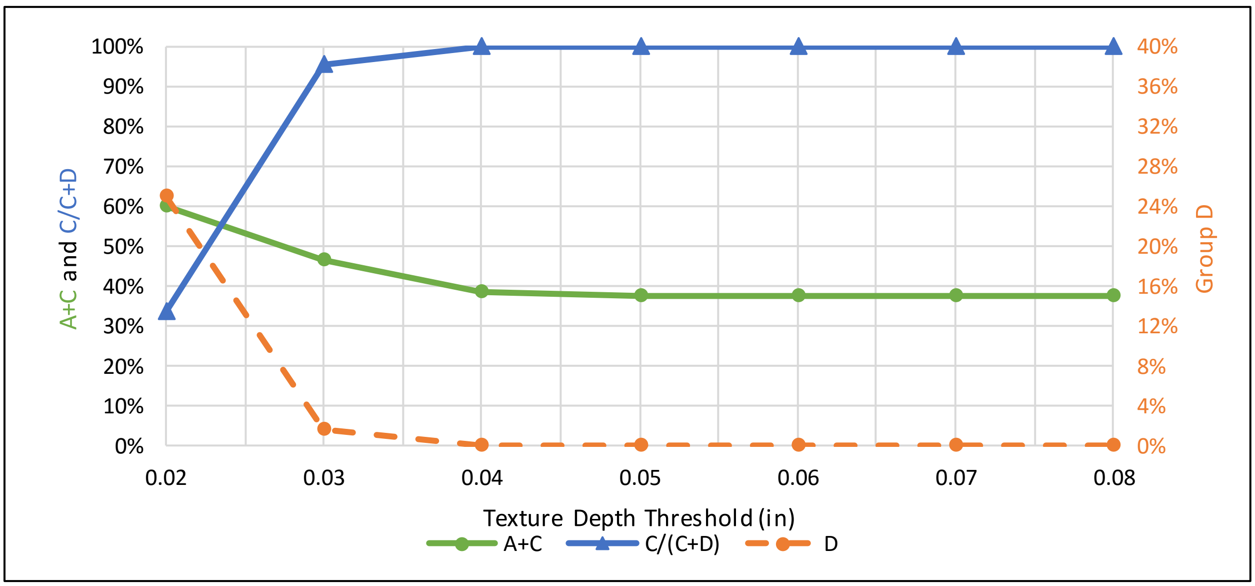


Figure 5.13 Varying Texture Depth Threshold for Untreated Concrete Pavements with 2017-2012 Seal Year

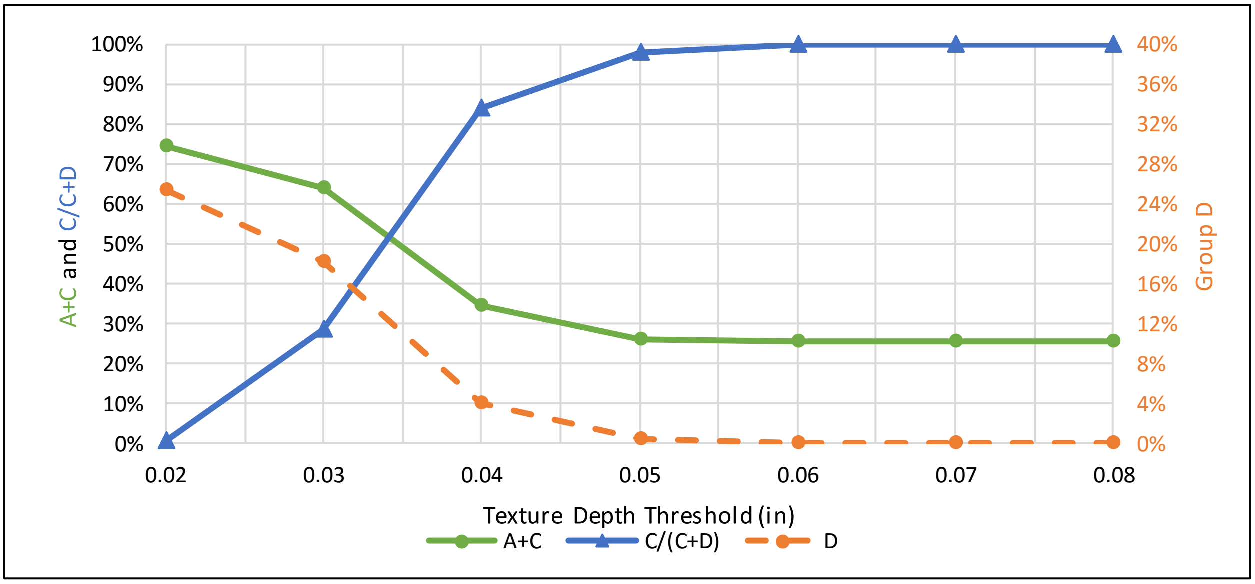


Figure 5.14 Varying Texture Depth Threshold for Microsurface Pavements with 2017-2012 Seal Year

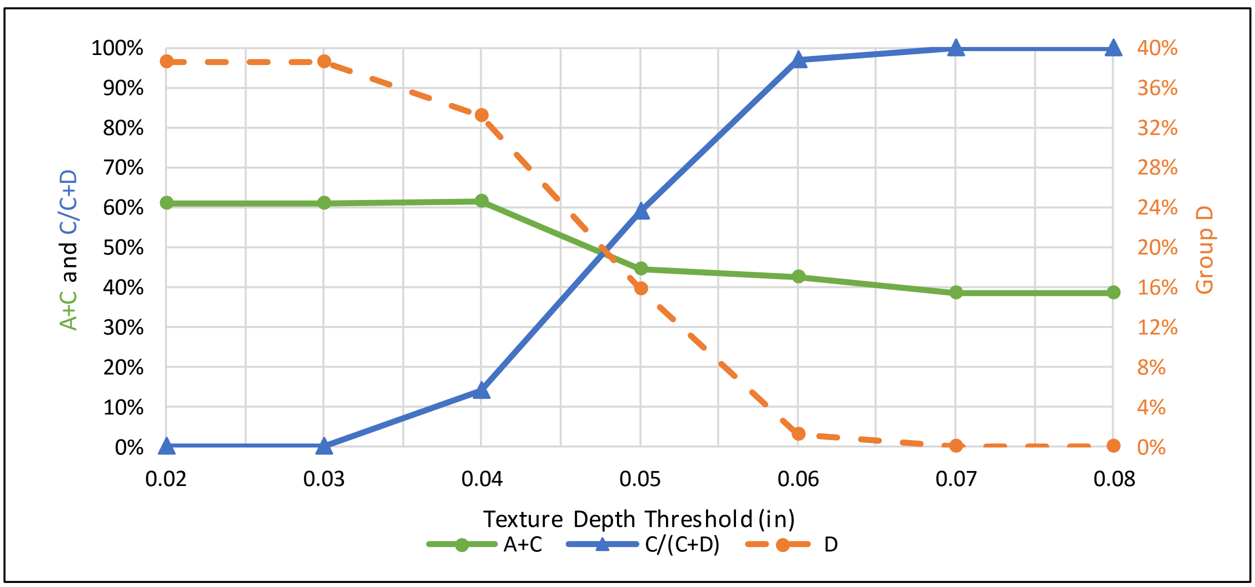


Figure 5.15 Varying Texture Depth Threshold for SMA Pavements with 2017-2012 Seal Year

5.4 Applications to Skid Data Collection

As mentioned previously, the relationship between texture and skid data varies by surface type and date of the most recent seal year. As such, only chip seal pavements with a seal year between 2012 and 2017 were carried forward to this part of the analysis. Chip seal pavements were used for two reasons. First, chip seal pavements exhibit the most consistent skid data and texture data relationship patterns of all surface types. Second, chip seal pavements have the most data points – more data points than the other surface types combined. This provides a more robust analysis and maximizes the application of results to skid data collection.

Chip seal data points prior to a 2012 seal year were excluded because the number of data points begins to diminish with older seal years. Likewise, the skid data and texture data correlation weakens with older seal years.

5.4.1 Case Study With 2017 Skid Data

A case study of the value of using a texture screening threshold for 2017 skid data collection was conducted. The case study evaluated 2017 skid data points for chip seal pavements with a seal year between 2012 and 2017 that also had a 2017 corresponding 2017 macrotexture data point. This represented about 1,200 miles of highway.

Applying a 0.05 inch texture depth threshold to the case study areas, 70 percent of the segments fall above the 0.05 inch texture depth threshold and would therefore be screened out under this scenario. This represents 825 miles of the 1,200-mile analysis segment that are screened out. The remaining 35 percent of the segments (about 375 miles) fall below the 0.05 inch threshold and would be measured. Figure 5.16 shows the statewide distribution of screened out and measured chip seal segments based on the criteria mentioned above.

The results of the case study were broken down further by focusing in on a smaller area to analyze which segments would be screened out and measured. Figure 5.17 shows an example of a closer view of the vicinity around US-191 from I-70 to La Sal Jct. in southeast Utah. As can be seen in Figure 5.17, most segments are screened out (red), but there are also pockets of blue that would still need to be measured. Thus, the question is raised, if the skid data collection driver must drive through screened out segments to reach segments to measure, should all segments be measured anyway? The impact of this consideration is discussed in the subsequent sections.

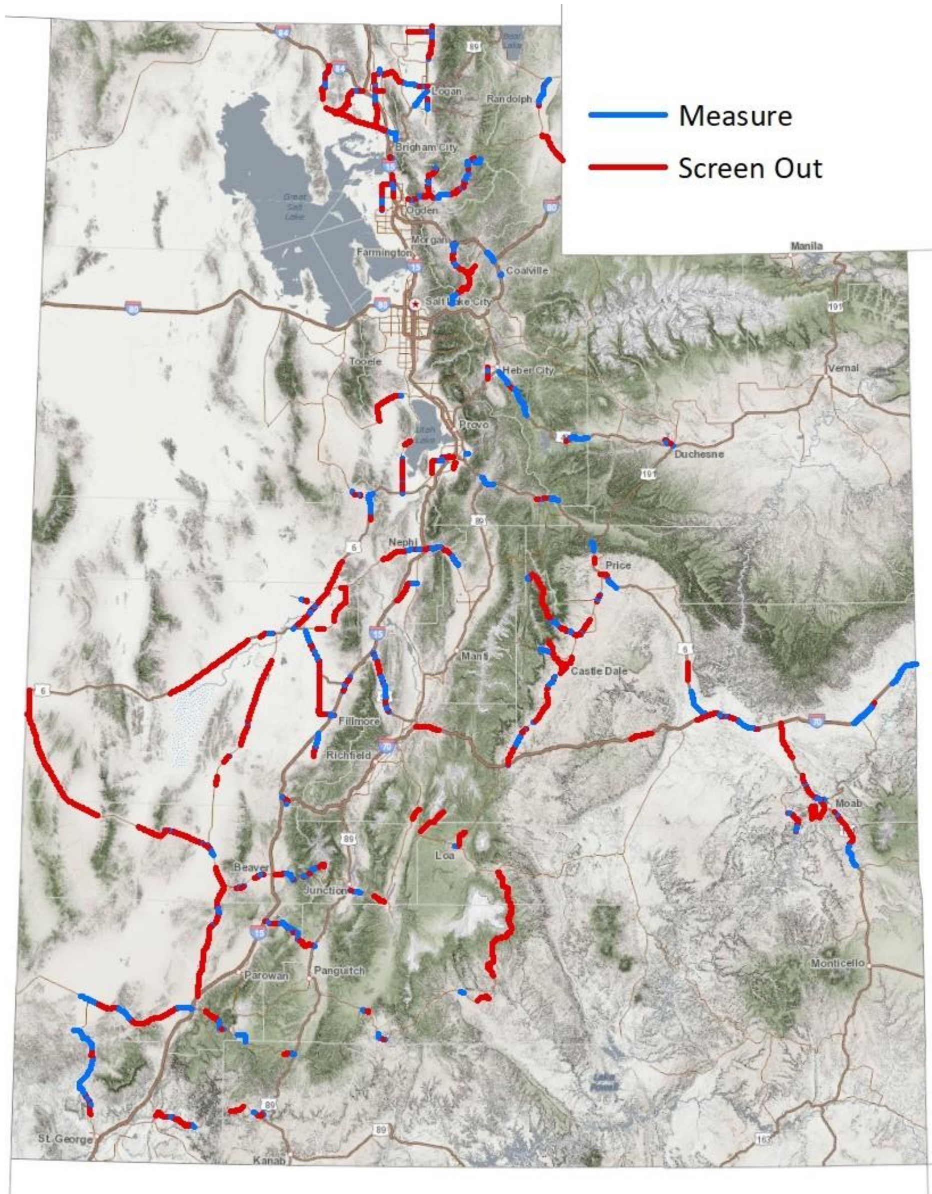


Figure 5.16 Screening Exercise for 2017 Skid Data – Chip Seal Pavements with Last Seal Year 2012-2017

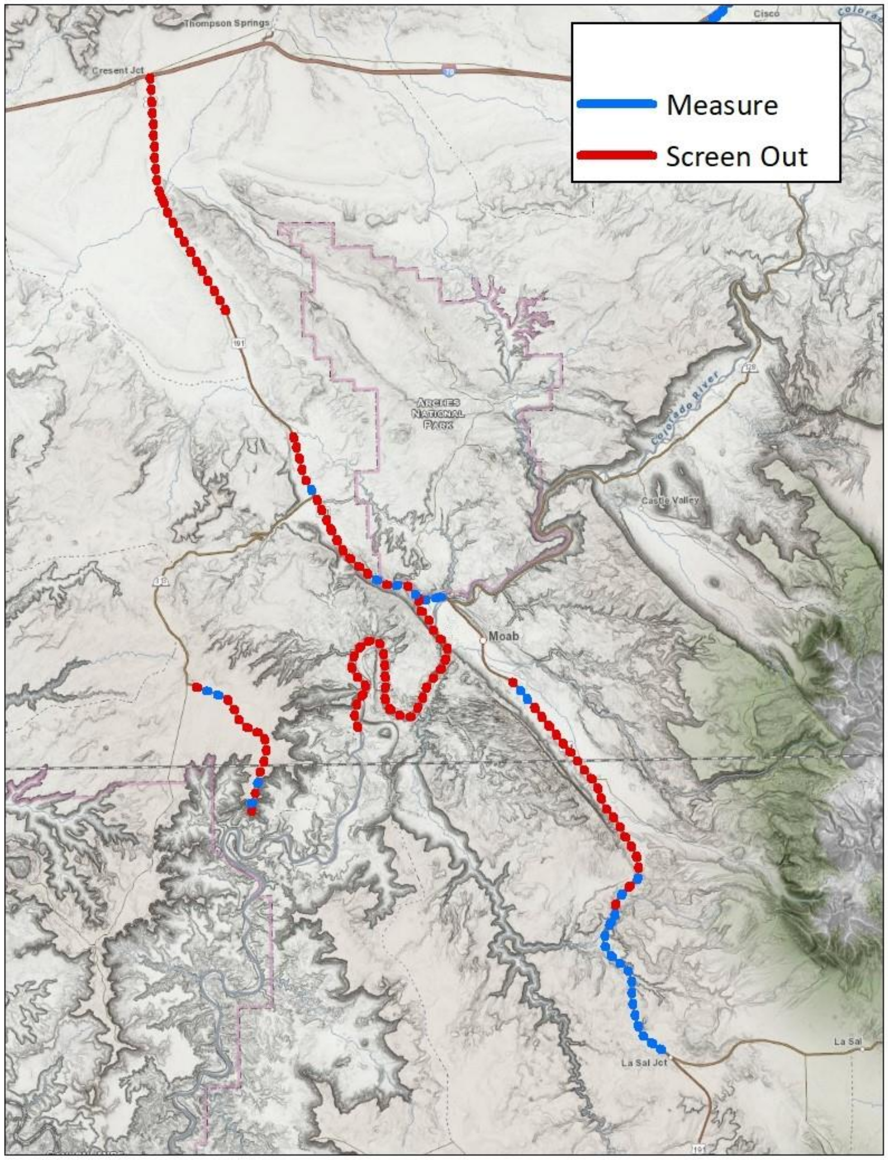


Figure 5.17 Screening Exercise for 2017 Skid Data – US 191 near Moab

5.4.2 Case Study With 2016 Skid Data

As mentioned previously, 2017 skid data collection effort was abbreviated compared to most years. As such, a second case study was conducted using skid data from the 2016 data collection effort. The 2016 skid data collection effort was more robust than 2017 and more representative of a typical skid collection year so screening results should be more reflective of the value expected to achieve in a typical year. However, additional caution must be exercised interpreting the results since the 2016 skid results are one year offset for the corresponding 2017 texture data.

Similar to the 2017 skid data case study, a 0.05 inch texture depth threshold was used to determine which areas would be screened out. Of the total 2,100 miles of chip seal pavements with a 2012-2017 seal year that were part of the 2016 skid data collection effort, approximately 67 percent of segments would be screened out and 33 percent would be measured. This equates out to about 1,400 miles being screened out and 700 miles that would still be measured. Figure 5.18 shows the chip seal segments that would be measured or screened out based on the aforementioned criteria for the 2016 skid data case study.

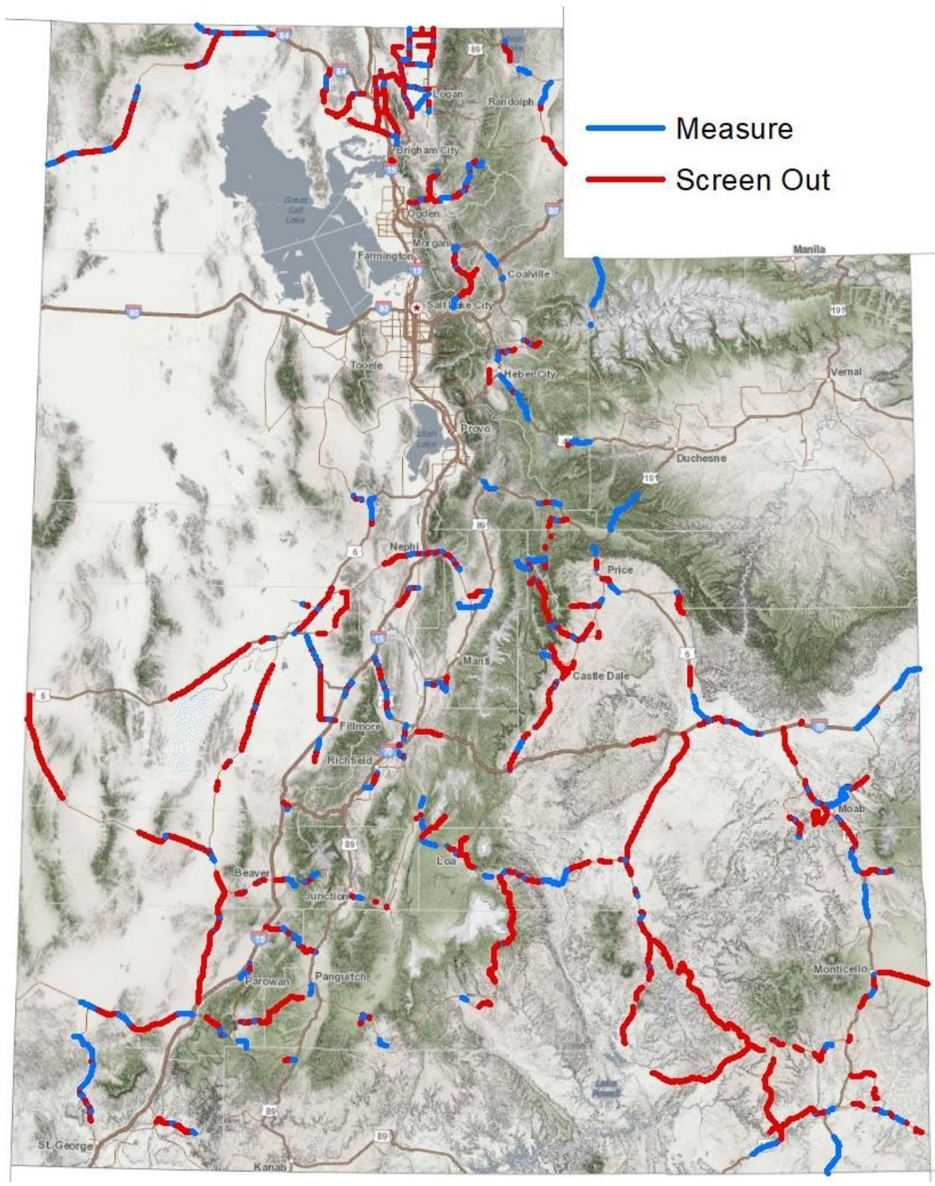


Figure 5.18 Screening Exercise for 2016 Skid Data – Chip Seal Pavements with Last Seal Year 2012-2017

5.5 Cost Benefit Analysis

To determine the potential savings of using texture depth thresholds to screen out road segments from future skid data collection, a cost benefit analysis was performed. UDOT pavement management staff provided a generic cost estimate for skid data collection of $17 per mile. Using criteria from the 2017 case study, 825 miles of the total 1,200-mile analysis length can be screened out. Multiplying the 825 miles screened out by the $17 per mile skid data collection estimate would represent a cost savings of approximately $14,000.

In practicality, not all the segments screened out by the texture depth threshold of 0.05 inches would be able to be skipped over during a skid data collection season. As mentioned previously and illustrated in Figure 5.17, some sections that are screened out by the threshold, may still be driven through for the skid data collector to reach areas that were not screened out. Driving through areas screened out for data collection, though not collecting skid data, likely still incurs some cost.

A conservative approach to segment screening is illustrated in Figure 5.19. Figure 5.19 highlights in yellow an estimate of the screened-out segments that would not need to be driven through to collect data for other highway segments. This amounts to 30 percent of the segments screened out by the 0.05 inch texture depth threshold. The other 70 percent of screened out segments were assumed to still undergo skid data collection or else maintain the per-mile cost as segments where skid data is collected. The original cost savings of $14,000 for the 2017 case study reduces to about $4,500 for this conservative approach.

Similar results occur with the 2016 skid data case study. The mileage and cost savings for screened out segments are 1,400 miles at $23,800. Using the conservative approach, the mileage and costs savings are 410 miles at $7,000. Table 5.2 summarizes the cost savings benefit of the skid data screening case study.

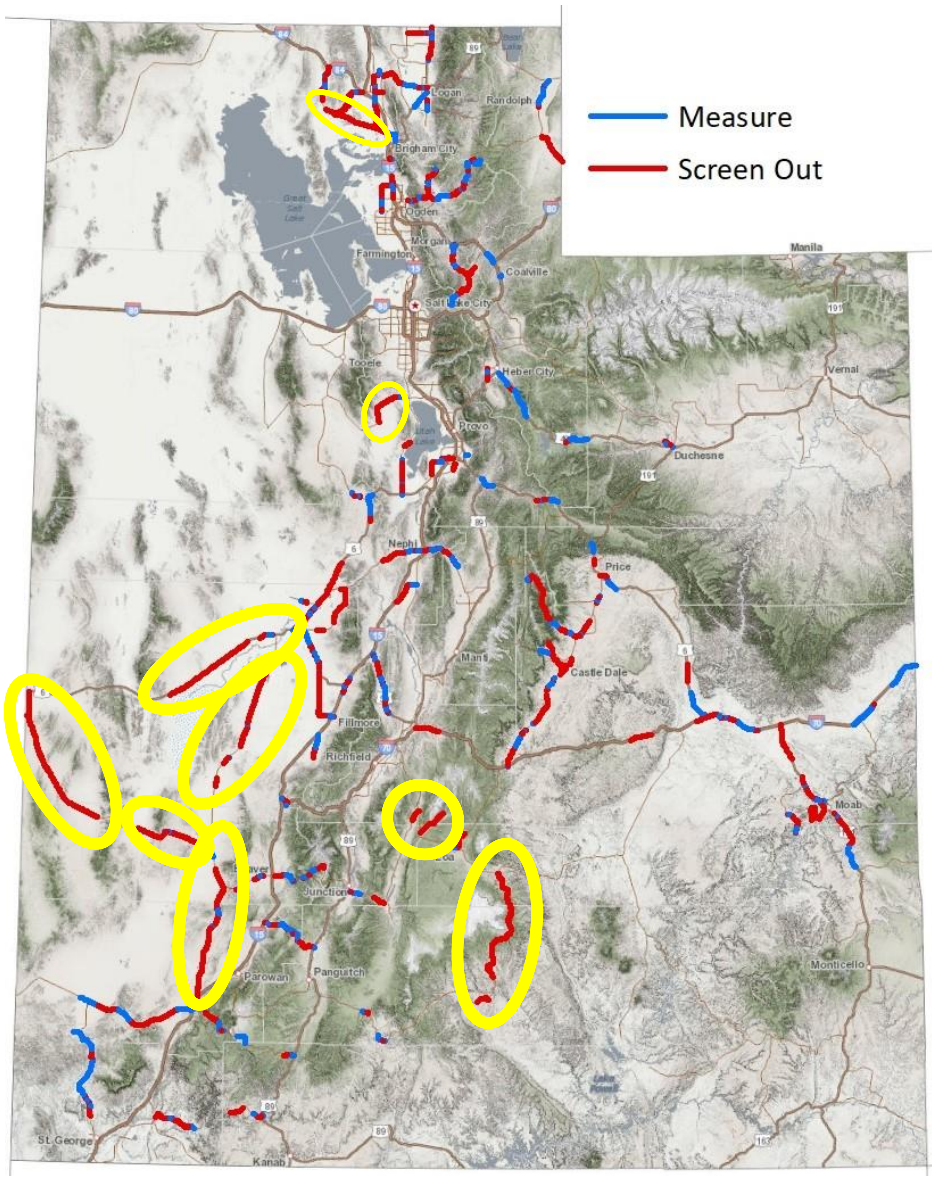


Figure 5.19 Screening Exercise for 2017 Skid Data – Conservative Screened Areas

Table 5.2 Summary of Skid Data Case Study Cost Savings

	2017		**2016**	
	Mileage	**Cost Savings**	**Mileage**	**Cost Savings**
Total Data Collection	1,200	--	2,100	--
Screened Areas	825	$14,000	1,400	$23,800
Conservative Screened Areas	265	$4,500	410	$7,000

5.6 Targeted Data Collection Areas

Similar to using texture depth as a threshold for screening out data collection areas, using a texture depth threshold to target areas to measure skid data at closer intervals was investigated. In this analysis, data points with texture values less than the chosen threshold would be areas where skid could be collected at more frequent intervals – perhaps 0.1 miles. Data points with texture values greater than the chosen threshold would be areas where skid data could be collected at normal intervals – 0.5 miles.

Two surface types were further evaluated: chip seal and SMA. Figure 5.20 and Figure 5.21 detail which data points for chip seal and SMA pavements would be measured more frequently based on the texture depth threshold of 0.04 inches.

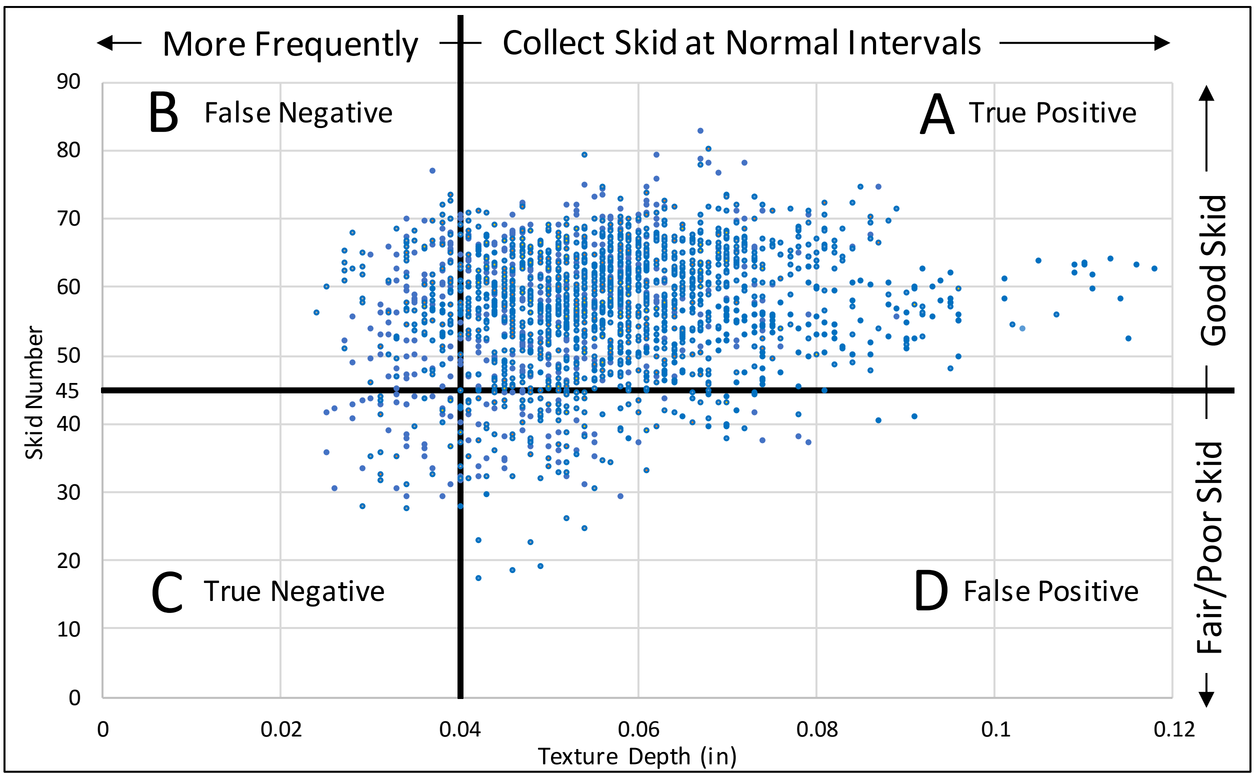


Figure 5.20 Targeted Approach Threshold for Chip Seal Pavements with 2017-2012 Seal Year

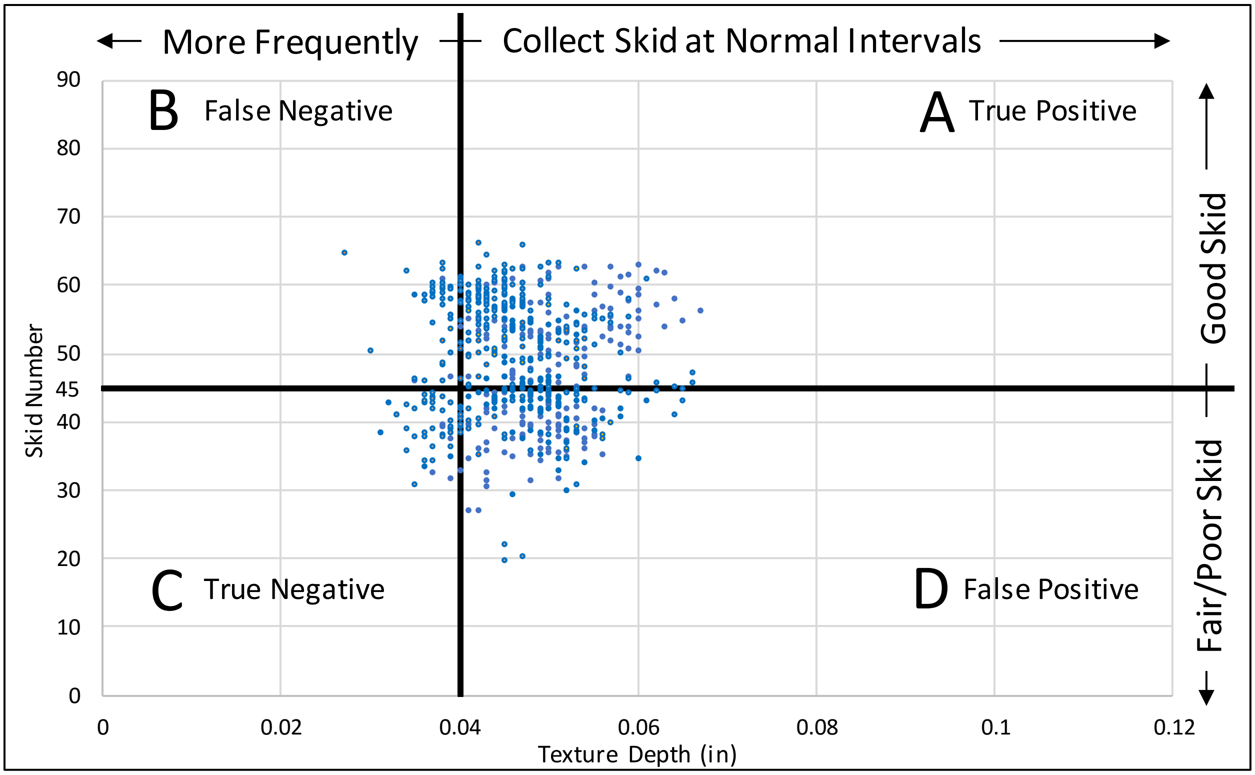


Figure 5.21 Targeted Approach Threshold for SMA Pavements with 2017-2012 Seal Year

5.6.1 Targeted Approach - Chip Seal

Data points were evaluated for chip seal segments that had a last seal year between 2012 and 2017, and a 2017 skid measurement. For a more targeted approach, a texture depth threshold of 0.04 inches was chosen. This threshold was determined by trying to maximize the ratio of data points in quadrant C over those in quadrant B. (see Figure 5.20). Figure 5.22 shows the segments of chip seal pavement statewide that would be measured at greater intervals using the 0.04 inch threshold.

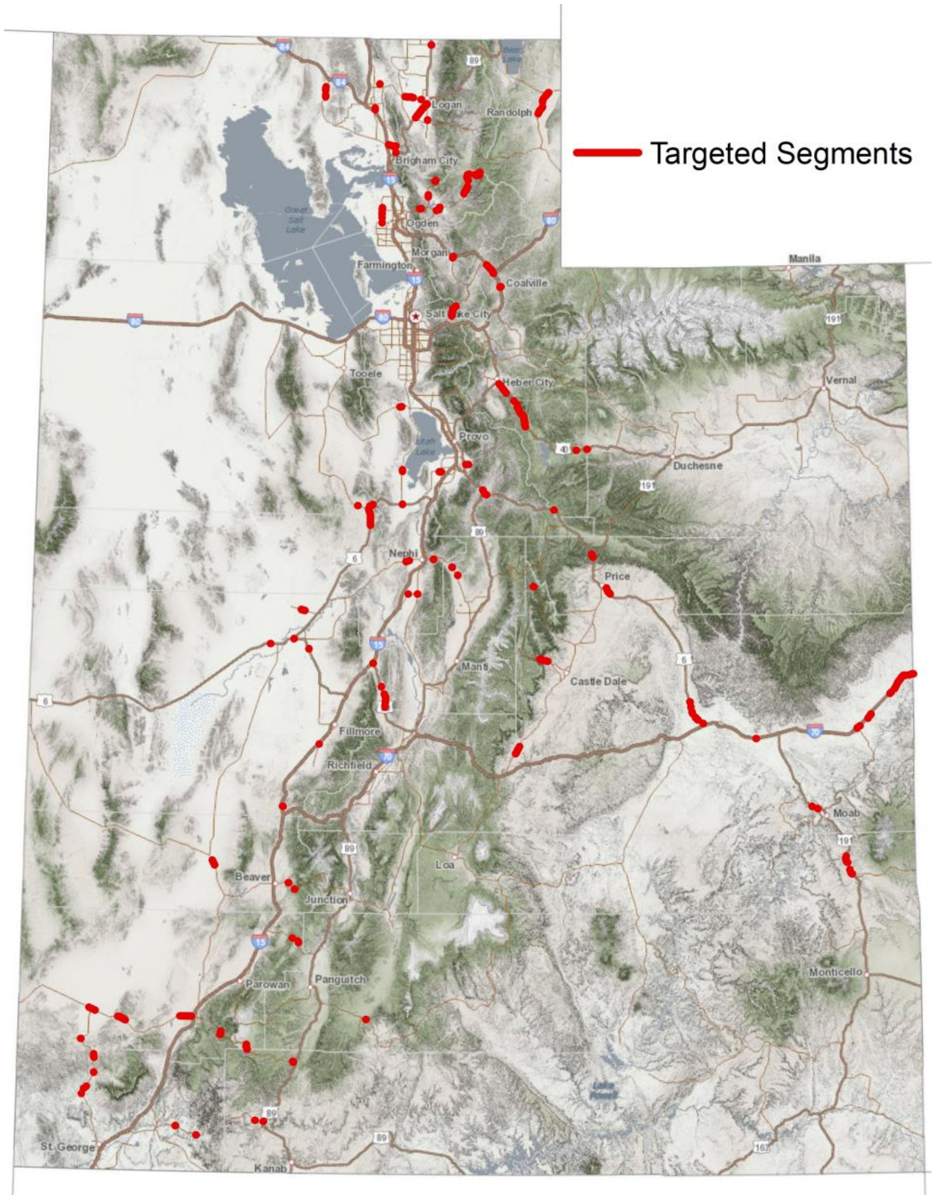


Figure 5.22 Targeted Areas – Chip Seal – Last Seal Year 2012-2017

Using the 0.04 inch texture depth threshold for chip seal segments results in 180 miles of targeted segments. Of these targeted segments, about 70 percent have a good skid score (quadrant B) and therefore did not need to be measured more closely. About 30 percent of the targeted areas have a poor or fair skid score (quadrant C), which are segments where it may be useful to measure skid data more closely. Therefore, a targeted approach using a texture depth threshold has limitations in its usefulness because a large portion of the segments targeted for measurement already have a good skid score and may not actually need to be measured more closely.

5.6.2 Targeted Approach – SMA

Data points were evaluated for SMA segments that had a last seal year between 2012 and 2017, and a 2017 skid measurement. As with chip seal, a texture depth threshold of 0.04 inches was chosen. Figure 5.23 shows the segments of SMA statewide that would be measured at shorter intervals using the 0.04 inch threshold. Using the 0.04 inch texture depth threshold for SMA segments results in 60 miles of targeted segments statewide. Of these 60 miles, 50 percent of the segments have a good skid score (quadrant B), and 50 percent of the segments have a poor or fair skid score (quadrant C). The targeted approach is more effective than for chip seal pavements, but results are still mixed. About half of the segments targeted for more frequent skid data collection had poor or fair skid values.

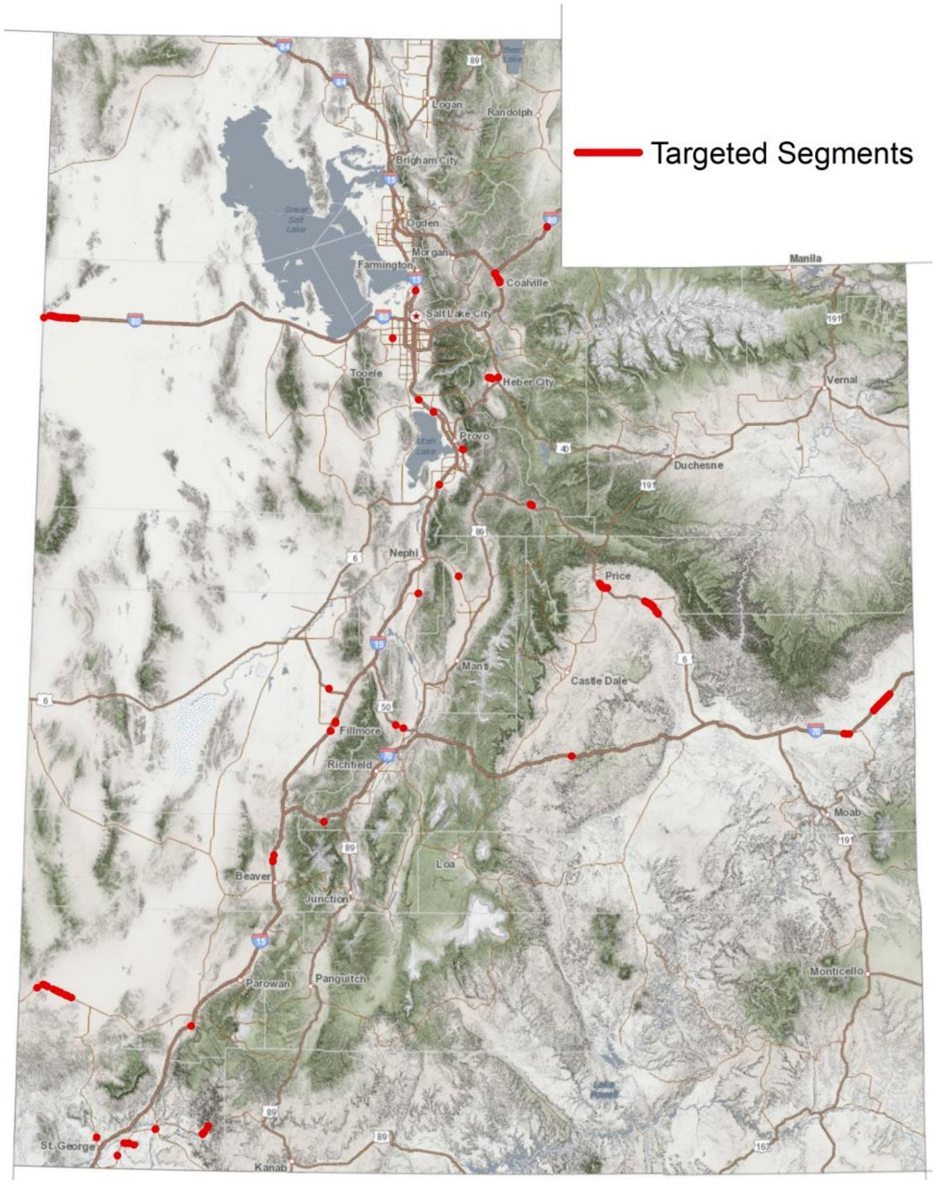


Figure 5.23 Targeted Areas – SMA – Last Seal Year 2012-2017

5.7 Safety Analysis

5.7.1 Wet Pavement Crashes vs. Texture Depth

The relationship between texture depth and the location of wet pavement crashes was examined on pavement segments to determine if wet pavement crashes occur more frequently where texture depth is low. The pavement segments used for the wet pavement crashes analysis were from the 2017 pavement section dataset provided by UDOT. Segments from this data set were five miles in length on average. Asphalts and concretes were examined for a five-year dataset of crashes (2013 to 2017). Figure 5.24 and Figure 5.25 plot the 2013-2017 Wet Pavement Crashes for asphalts and concretes. Asphalts and concretes were separated because previous analysis shows texture depths have very different ranges for each type. As can be seen from Figure 5.24 and Figure 5.25, there is only weak correlation present between texture depth and wet pavement crashes.

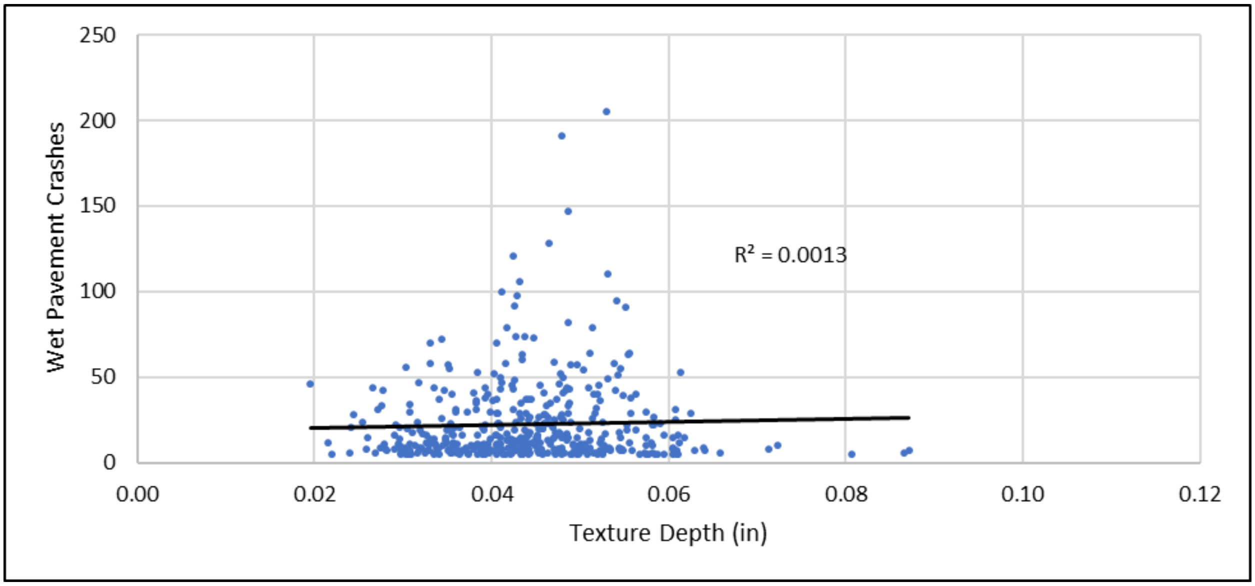


Figure 5.24 2013-2017 Wet Pavement Crashes and Texture Depth - Asphalts

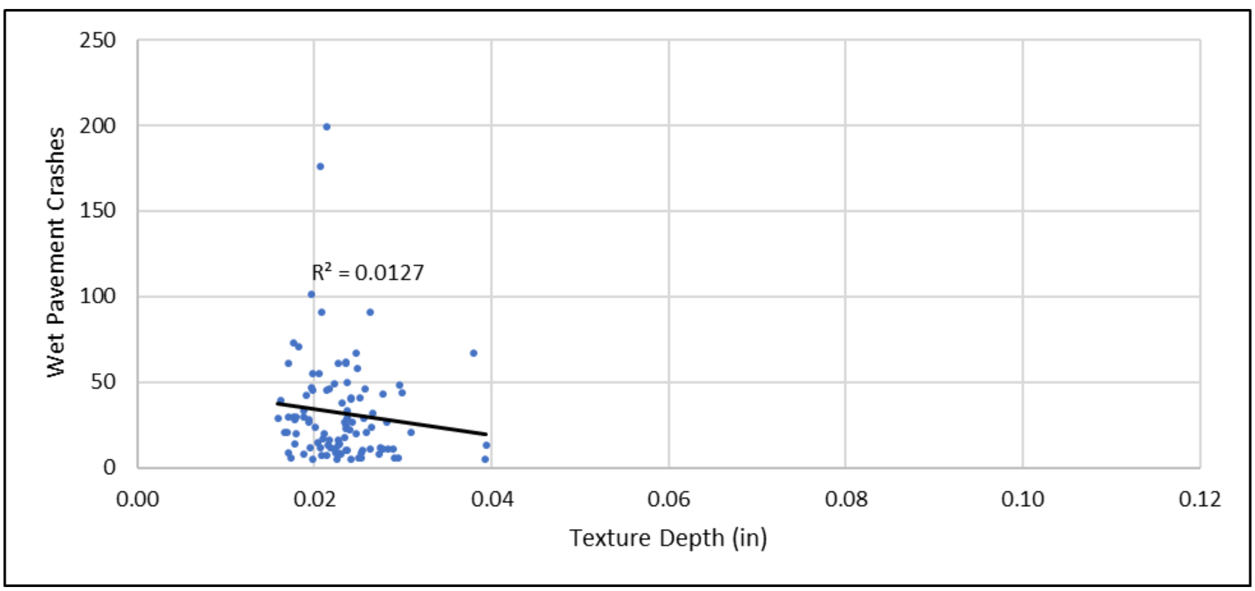


Figure 5.25 2013-2017 Wet Pavement Crashes and Texture Depth - Concretes

The texture depth and wet pavement crash relationships were also examined for the percent of wet pavement crashes. Utilizing percent of wet pavement crashes helps for locations that have a high number of wet pavement crashes primarily because they are a high crash location for all crash types. Only segments that had a minimum of five wet pavement crashes were considered in order to avoid skewed percentages. Figure 5.26 and Figure 5.27 plot the relationship between texture depth and percent wet pavement crashes. Once again, there is little to no relationship when examining texture depth and wet pavement crash rates.

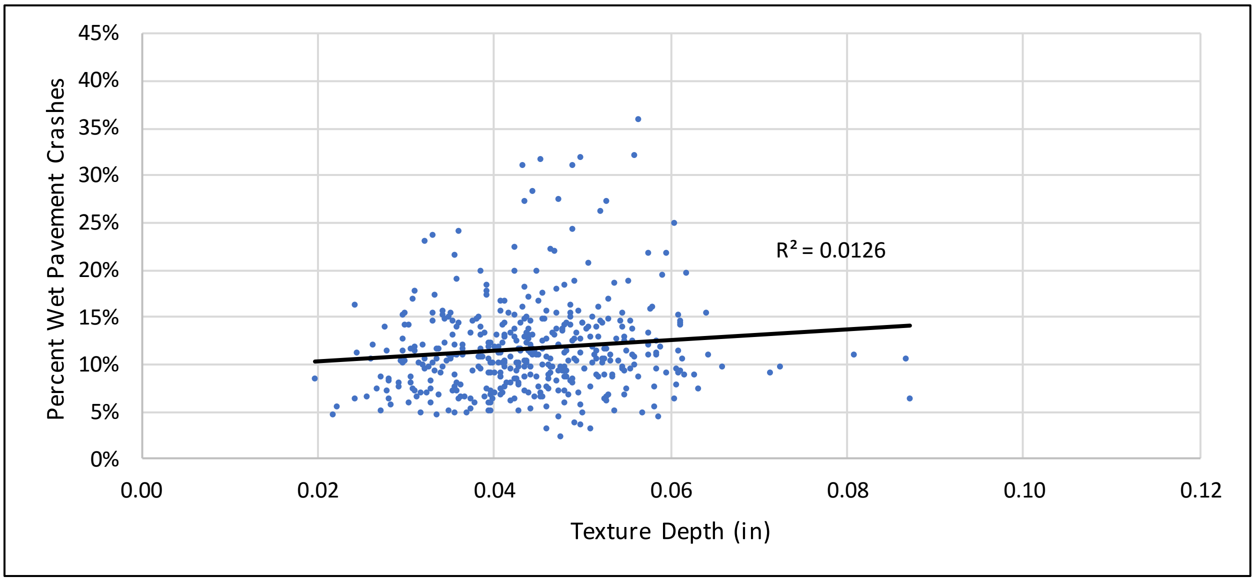


Figure 5.26 2013-2017 Percent Wet Pavement Crashes and Texture Depth - Asphalts

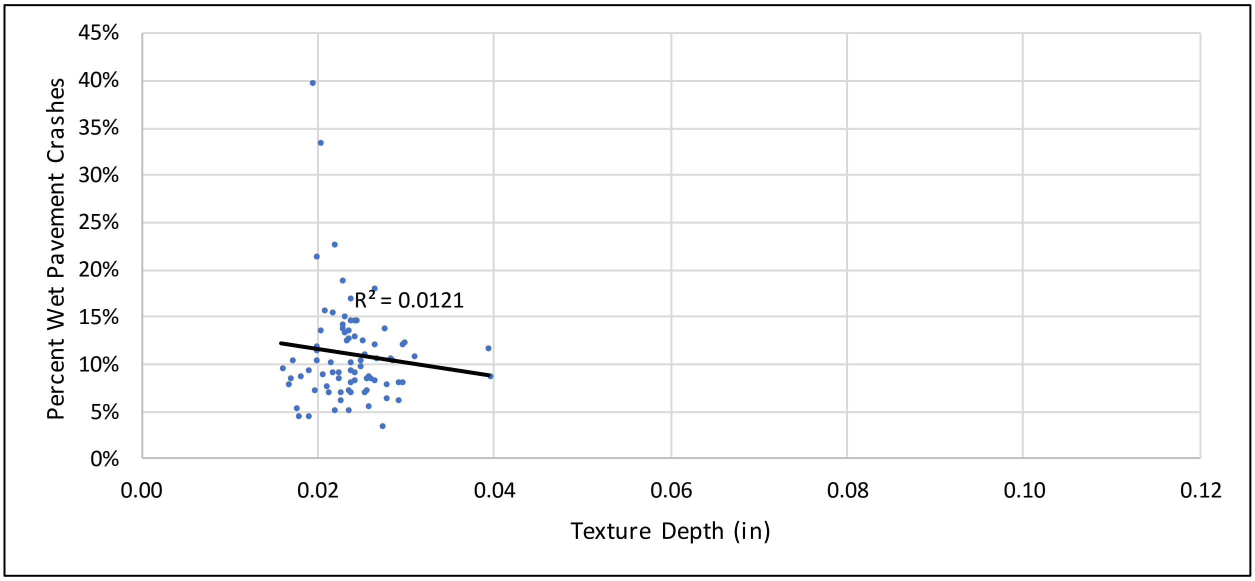


Figure 5.27 2013-2017 Percent Wet Pavement Crashes and Texture Depth - Concretes

6.0 CONCLUSIONS

6.1 Summary

Skid resistance and pavement texture data are important measures of pavement surface characteristics. The purpose of this study was to develop an understanding of how new pavement texture data can be used to inform roadway safety and develop a more targeted approach to SN assessment with focus on high risk areas. Data for SN and pavement texture was provided by UDOT. A statistical analysis examined the correlation between skid data and pavement texture. Texture depth thresholds were explored to help screen and refine skid data collection efforts. Case studies were performed to demonstrate the potential benefits of using texture data to screen out segments from future skid measurement. Data screened from these efforts was used to develop potential cost savings metrics. Texture thresholds were also evaluated to target areas for more refined skid data collection. Finally, the relationship between pavement texture depth and wet pavement crash history was examined.

6.2 Findings

Findings from the statistical analysis indicate that there is not a strong correlation for SN and texture depth when looking at all pavement segments statewide. Pavement texture however is sensitive to surface type and some surface types represent a stronger correlation than others. Chip seal and untreated concrete show the strongest correlation, especially when broken out by individual seal year.

Focusing on last seal year, more recent seal years tend to exhibit more data points and stronger correlations than less recent seal years. Chip seal pavements show a weak positive correlation between texture depth and SN for each of the last seal years 2011 to 2017.

Screening thresholds were developed for texture depth to help screen and refine skid data collection efforts. When looking to screen out segments from future skid data collection, finding an optimal texture depth threshold is essential to minimize false positives (areas of poor or fair skid that should have been measured). The relative value of the threshold can be summarized in the effort saved by not having to collect data for true positive measurements that have a good SN and the risk in accepting some number of false positives – areas that have a bad SN but were screened out.

Using a texture depth screening threshold of 0.05 inches to screen out segments from future skid collection can result in a high number of segments being screened out during a given year (70 percent in the chip seal example). Based on an hourly operating cost of $17 per mile for skid data collection, this would result in a savings of approximately $14,000 in data collection efforts when applied to the 2017 skid data collection efforts case study. Applying similar methods to the 2016 skid data collection, which was more comprehensive than 2017 data collection, the estimated savings are $23,000. However, given that the skid collection driver would still have to drive through many screened out segments to get to segments targeted for measurement, the effort saved would be less. A conservative estimate reduces the 2017 and 2016 cost savings to approximately $4,500 and $7,000, respectively.

The texture depth screening threshold can also be used for a targeted approach to find areas to measure skid at more frequent intervals. Chip seal pavements and SMA pavements were examined and a texture depth of 0.04 inches was identified as a threshold for more frequent skid data collection. Applying this threshold to the 2017 skid-data-collection-case study results in 180 miles of chip seal pavements and 60 miles of SMA pavements that would be targeted for more frequent skid-data collection. This method was less efficient for the chip seal case study because 70 percent of the areas that would have been targeted corresponded with good skid. For SMA, the split between areas with good skid and poor or fair skid was at 50 percent.

Texture depth measures were aggregated to longer roadway segments defined by homogenous pavement types and ages. The total wet pavement crashes for each segment was compared to the average texture depth, but the result did not produce a strong correlation. Likewise, there was not a strong correlation between texture depth and the percent of wet pavement crashes.

6.3 Recommendations

There is utility in the texture depth data that is now being gathered every year. Despite no strong correlation between texture depth and SN being manifest in this study, there is still enough of a relationship to apply meaningful thresholds to both screen skid data collection efforts and target skid data collection efforts to potential poor or fair skid areas. It is recommended that UDOT analyze and utilize annual texture data to tailor the annual skid data collection efforts. Further effort will be needed to determine how modified efforts affect real routing plans for skid data collection drivers.

The correlation between wet pavement crashes and texture depth was also found to be weak, but it is recommended that further study is applied to the relationship between wet pavement crashes and pavement texture depth at specific areas. Potentially, texture depth does not play a major factor for wet pavement crash history except for high-risk locations, such as horizontal curves or intersections. At these locations, vehicles are more likely to be affected by low-grip pavements because drivers are engaging in turning or stopping maneuvers. On tangent roadway sections with no traffic control, tire grip on wet pavements has less of an impact on driver control. Additionally, to develop a more robust crash data set, five years of wet pavement crashes were analyzed (2013-2017) even though the pavement texture data was from 2017 only. It is possible the crash history for the four years leading up to 2017 reflects different conditions than when the 2017 pavement texture data was collected.

6.4 Implementation Plan

The following steps should to occur to implement screening and targeted skid data collection according to texture data thresholds:

1. Acquire statewide texture data on an annual basis
2. Process texture data and join to pavement surface type data
3. Apply a texture depth threshold of 0.05 inches to identify chip seal segments that can potentially be screened out from skid data collection efforts
4. Map the potential screened out segments
5. Review the skid data collection routing schedule and identify areas available to screen out based on practical routing patterns and schedules
6. Apply a texture depth threshold of 0.04 inches to SMA segments to identify areas for potential targeted data collection

7. Map the potential targeted areas
8. Review the skid data collection routing schedule and identify areas available to target more frequent skid data collection based on practical routing patterns and schedules

This process will require coordination between the skid data collection and processing staff and the texture data collection and processing staff. Data analysts and GIS analysts will be needed to analyze, combine, and compare texture data and skid data. The skid-data collection operator will need to be included in the screening results in order to identify which adjustments to the data collection plan for that year are implementable from a practical routing standpoint.

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